EVALUATION FRAMEWORK FOR ENERGY TECHNOLOGIES FOR HILL DISTRICTS

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Prepared for

The Second Regional Workshop on
District Energy Planning and Management of
Mountain Districts of Hindu Kush - Himalaya
to be held at,

International Centre for Integrated
Mountain Development,
Kathmandu during 14-18 January, 1988

Tata Energy Research Insitute
7, Jor Bagh, New Delhi 110 003

December, 1987

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1. INTRODUCTION

In a district, the availability of commercial sources of energy (electricity, diesel, oil, gas and kerosene) is decided at the state/national level and may be limited depending on the national situation, while the supply of traditional fuels is determined by the biomass resources in the district. In addition few renewable energy resources (solar, wind, hydro etc.) may be available. Hence if one takes the commercial fuels as given, a district energy planner has following options to consider while developing an energy development strategy for a district -

i) To enhance the supply of traditional energy sources.

ii) To exploit the renewable energy resources in the region.

iii) To improve the energy efficiency of the conversion technologies for various enduses.

Of these three, the technology oriented options (ii & iii) offer an immediate solution with long term implications on the energy consumption pattern. Use of renewable energy resources can result in more self sufficiency in regional development without increasing the demand for commercial energy sources. The increase in energy efficiency in domestic sector will give rise to fuel savings as well as improved quality of life. In the economic activities adoption of energy conservation measures or use of viable renewable energy technologies will increase the economic gain per unit of energy cost.

In order to carry out the exercise of energy planning for a district, a knowledge of various technology options available for meeting the energy requirements of a given enduse along with the various features of the enduse is essential. There will be two types of technology options (i) options to enhance energy supply options at a regional level eg. a decentralised power generation system to augment the power supply in the region (ii) technology options to meet household, community or industrial energy demand eg. water pumping for irrigation, or biogas plants for cooking. Hence it is important to evaluate the options by considering various aspects of the existing energy supply system for an end use.

From the various options available for an enduse, the final choice would depend on the availability of resources needed by the technology, its suitability to existing practices of energy use, its economic viability and the infrastructure requirements for adopting that option as a replacement to the traditional methods/technologies. Above all the environmental and ecological implications of any alternative energy supply system would play a decisive role in the choice of options. The acceptance of a technology at a household would depend on the economic gains, the convenience of use to the enduser while the options for augmentation of energy supply would depend on broader environmental, socio-political and economic considerations besides technical viability.

The purpose of this paper is to compile technical information on enduses and energy conversion technologies relevant to the regions in Hindu Kush Himalaya and to provide an illustrative framework for evaluation of energy technology options. A check list of factors other than energy-economic considerations is attempted for each enduse. The available energy conversion devices for different enduses are listed in Table 1. It is to be noted that power generation is listed as an enduse for convenience.

Table 1 : Energy Technology Options for Different End Uses

Cooking	Space heating	Water heating	Lighting	Water pumping	Milling	Power generation (Contd.)
Stoves based on		Stoves burning				
crop residues,	Coke/coal		Biogas mantle		Microhydel	Diesel based
dungcakes)	Biomass		LPG lamps			
	Biomass		Electric bulbs			Wood gasifier system
briquettes	Kerosene	LPg				
	heaters	Solar water		. Diesel		Direct combustion
	Solar	Heaters		Electricity	Biomass	of agrowastes
Biogas	methods			. Biogas + Diesel		System based on gasification
				. Produce gas +		briquetted agrowastes
Electric oven/				Diesel		Solar PV system
Flat plates						Solar control receiver
						system
				Windmills		Solar dish stirling
Solar Cookers				Solar PV systems		Solar parabolic
						trough
				Solar thermal		
				systems		Solar pond power
						system

* Similar to cooking

2. ENDUSE CHARACTERISTICS

Different enduses are clubbed here under various sectors - household, agriculture, industrial and commercial. The enduse characteristics consist of various features of the existing energy supply system. This includes availability of energy resources, description of energy conversion devices and the energy requirements for a typical use pattern. Also mentioned are other components relevant to the energy supply system.

2.1 Household Energy Systems :

In majority of the rural households in hilly areas an energy system consists of one or more biomass stoves performing multiple functions of supplying energy for

- cooking and water heating
- spaceheating and waterheating (in many areas)
- cooking and spaceheating
- lighting (some times)

As an household economy develops depending on the availability of better fuels, separate devices are used to meet the energy demand of these enduses. This can be seen in the urban household sector more markedly where spaceheaters, waterheaters, lamps and gas stoves for cooking are used. We have also considered these enduses separately as the technology options may be able to perform the multiple function.

Cooking :

The parameters other than stoves characterising different components of a cooking system are listed in Table 2.

Table 2 Attributes of components of cooking systems

Component	Parameters
Fuels	Size, shape, access, seasonal variation, availability, price, calorific value
Food	Typical items, cooking procedures and preferences
Pots	Size, shape, material
Food Habits	Time of meals, seasonal variation
Cooking Practices	Preferences of cooks (particularly position with respect to firebox)
Kitchen	Size, other uses, multiple choices

Although, from an energy conservation objective changes in all these components are possible, the current emphasis is only on stoves.

Stoves are characterised by thermal efficiency determined by the Water Boiling Tests. But cooking involves operations other than boiling performed under different field conditions. Hence the extent of energy conservation resulting from more efficient stoves in actual practice will not be as expected under laboratory conditions. Table 3 summarizes the standards for some of the cooking stoves based on different fuels. To

Table 3 : Standards for Cookstove Performance

S.No	Energy Source	Certifying Agency	Performance Index	Standard
1.	LPG	ISI	Efficiency	> 60%
			CO/CO_2	< 0.02
2.	Kerosene	ISI	Efficiency	40-65%
			CO	< 20 ppm
3.	Biogas	ISI	Efficiency	> 55%
			CO	< 500 ppm
			Efficiency in roti making	> 40%
4.	Biomass heavy stoves	DNES	Efficiency	> 20%
5.	Biomass metal stoves	DNES	Efficiency	> 30%

understand the energy conservation potential it is important to know cooking energy needs of different items. Typical food preparation processes are i) Boiling (stewing, paraboiling) ii) Frying (Deep frying, Saucepan frying, Flatplate frying), iii) Baking (Roasting) and iv) Grilling.

The data also is inconclusive and points towards a need for a local evaluation of technology options for cooking. The tables 4A to 4E give energy requirements for cooking various food items and typical fuel consumption in controlled cooking tests. The economies of scale exist for boiling operations like cooking rice and pulses. Use of spherical pots saves energy. The data given is for planes while the energy requirements in hills will be higher due to lower initial temperatures of raw materials and more heat losses to atmosphere due to low ambient temperatures. Table 5 gives the calorific values for different food items and nutritional requirements of average adults. In India 620 kcal of useful cooking energy is suggested as per captia per day norm by the Advisory Board on Energy. Besides energy conservation other parameters of importance are time, cleanliness, emissions etc.

Space Heating :

Space heating is a seasonal need and varies with altitude and ambient temperatures. In some hill areas the fuelwood stove serves the dual purpose of space

Table 4A : Fuel and Energy Consumption in Cooking Rice

S.No.	Parameter	Data from different experiments						
1.	Pot	Flat Al	Spherical Al	Spherical	Pressure Clay	Flat Al Cooker	Spherical Al	Spherical Clay
2.	Stove	Conventional one (one port)	Conventional one (one port)	Conventional one (one port)	Conventional one (one port)	Improved Stove	Improved Stove	Improved Stove
3.	Rice(kg) Water(kg)	1.14 4.88	1.36 5.90	1.36 5.90	0.91 2.27	1.14 4.88	1.36 5.9	1.36 5.9
4.	Fuel type Quantity (kg)	dry wood 2.3	dry wood 1.6	dry wood 1.6	dry wood	dry wood	dry wood	dry wood
5.	Time (min)	46	44	44	24	47	45	55
6.	Energy usage (kcal/kg dry rice)	8578	6001	6001	5380	4622	3705	3719
8.	Thermal Efficiency (%)+	8	13	12.5	12			

Source : Islam (1984)

+ This is based on Water Boiling Tests under control conditions

Table 4B : Fuel and Energy Consumption in Making Rotis

S.No.	Parameter	Data from Different Experiments				
1	Pot	Flatplate	Flatplate	Flatplate	Flatplate	Flatplate
2	Stove	Traditional (one port)	Traditional (one port)	Improved (one port)	Improved (one port)	Traditional (one port)
3	Amount Cooked (Wheat Flour) (kg)	1	3	1	3	1
4	Fuel (kg)	.1(wood) + 1.5 (dung)	.2 (wood) + 4.4 (dung)	.1(wood) + 0.99(dung)	.2(wood) + 2.9(dung)	1.1 wood
5	Time (min)	50	140	40	112	
6	Energy Use kcal/kg dry flour	3775	3606	2588	2398	3902
7	kcal/kg wet dough (dough : flour ratio)	2157 (1.75)	2060 (1.75)	1522 (1.75)	1439 (1.75)	2601 (1.75)
8	kcal/roti (rotis/kg dry flour)	151 (25)	144 (25)	104 (25)	96 (25)	325 (12)
9	Thermal efficiency (based on WBT)	8.1 ± 1.1	8.1 ± 1.1	18.0 ± 1.7	18.0 ± 1.7	8
10	Reference	Arya (1985)	Arya (1985)	Arya (1985)	Arya (1985)	Morse (1984)

Table 4C : Fuel and Energy Consumption in Cooking Pulses

S.No.	Parameter	Data from Different Experiences							
1.	Pot	-	-	-	-	-	-	Spherical Al	Spherical Al
2.	Stove	Traditional (One port)	Traditional (One port)	Traditional (One port)	Improved (One port)	Improved (One port)	Hari (A traditional dungcake stove)*	Traditional (Bangla Deshi)	Traditional (Bangla Deshi)
3.	Quantity (kg) (Water : Dal)	0.25 (mixed)	.25	0 75	0.25 (mixed)	0 75	0.25	0.45(Khesari) (6.7:1)	0.45(Masur) (6.7 : 1)
4.	Fuel used (kg)	0.1(wood) +1.3(dung)	1.4 dung	0.2(wood) +1.57(dung)	0.2(wood)+ 0.843(dung)	0.24(wood)+ 0.963(dung)	1.64(dung)	0.86 (wood)	1.13 (wood)
5	Time (min)	62	62	68	50	54	75		
6	kcal/kg raw dal	13444	12898	5668	9036	3807	15088	7067	8994
7.	kcal/kg cooked food	2490	2388	1119	1667	1002	2794		
8.	Reference	Arya (1985)	Arya (1985)	Arya (1985)	Arya (1985)	Arya (1985)	Arya (1985)	Islam (1984)	Islam (1984)

Table 4D : Fuel and Energy Consumption in Cooking Vegetables

S.No.	Parameters	Data from Different Experiments					
1.	Pot	-	-	Spherical pan (Al)	Spherical pan (Al)	-	-
2.	Stove (One port)	Traditional	Improved	Traditional	Traditional	Traditional	Improved
3.	Vegetable (kg) (Water : Veg)	1.0 (Potato)	1.0	1.36 (water 1:1)	4.1 (water 1:1)	(Pumpkin) 2.0	2.0
4.	Fuel (kg)	0.1(wood) + 1.54 (dung)	0.1(wood) + 1.08(dung)	1.31	1.85	0.1 (wood) + 1.78 (dung)	0.1 (wood) + 1.12(dung)
5.	kcal/kg raw vegetable	3865	2793	3454	1622	4403	2890
7.	kcal/kg cooked vegetable	1933	1396			2097	1376
8.	Reference	Arya (1985)	Arya (1985)	Islam (1984)	Islam (1984)	Arya (1985)	Arya (1985)

Table 4E : Energy requirements of different food items

Food	Energy in kcal/kg raw material Initial temperature = 25oC
Boiling	3245
Rice (with 1.5 times water)	
Frying	
Potatoes, french fried	18242
Fish fillets	17196
Shrimps	15397
Baking	
Bread	26150

Source : P Verhaart (1985)

Cooking energy and time for potaotes, rice and cabbage

Item	Cooking Temperature (oC)	Cooking Time (min)	Cooking energy kcal/kg raw material
Potatoes	82	105	904
Potaotes	87	45	1356
Rice	76-98*	30	1205
Cabbage	82-88*	45	1506

* The temperature distribution is non-uniform across the mass of rice and cabbage. The values given are the lowest and highest ones measured.

Source : Jain etal (1984)

Table 5 : Food Calorific Values

Item	Calorific Value (kcal/kg)
Rice	3,537
Whole Wheat Flour	3,410
Potato	970
Pulse (Masur)	3,430
Pulse (Khesari)	3,450

Reference : Islam (1984)

heating and cooking while in still colder areas space heating is achieved by separate stoves (Bhukhari in Jammu and Kashmir or Angethi in UP hills) which use fuelwood, sawdust, kerosene, coal or coal dust and cowdung in briquetted form. Space heating by means of solar energy is not found in traditional architecture in the hilly areas, however, energy conservation in the buildings is to some extent achieved by the use of local insulating materials in the construction. The space heating norm recommended by Advisory Board on Energy is 30 kcal per capita per day.

The commonly known method of calculating space heating loads is the degree day method.

The monthly space heating load is given by the relation

$$Q\text{month}= (UA + 1.105\ V)\text{KJ/hr}\,{}^{o}\text{C} \times \text{D D}\ {}^{o}\text{C}\ \frac{\text{day}}{\text{month}} \times 24\ \frac{\text{hr}}{\text{day}} \quad -(1)$$

where

U is the coefficient of heat transmission of the structural element

A is the total wall area in m^2

V is the volume of air infilteration in m^3/hr

DD is the degree days defined as the difference between a fixed base temperature 18.3 °C and the daily mean outdoor temperature, summed up for a specific period of time, such as a month. The summing is carried out only for the days for which mean ambient temperature is less than 18.3 °C. The difference between 24 °C and 18.3 °C allows for ordinary levels of internal heat energy generation in the building. The heat loss through the floor is neglected here.

The parameters that would effect the building space heating loads are

- solar insolation
- ambient temperature
- wind speeds
- building materials
- thickness of walls
- door and window area

Water Heating :

Water heating requirements in hill areas are usually met by the biomass stoves meant for cooking or space heating or both. In urban centres electricity, kerosene or coal may be used for this purpose . The effect of altitude on overall system efficiency would be again due to low ambient temperatures and low initial water temperatures and is discussed earlier. In traditional water heating systems fuel is always available, but if solar water heating is to be considered as an option then items listed in Table 6 need to be checked for matching solutions to the need.

Table 6 Components of Water Heating System

Components	Attributes
Water	Storage, Mode of water fetching and time
Bathing, Domestic Chores	Quantity, Temperature, time of use and locations of use
Architecture of the house	Availability of proper space

Lighting :

At the locations connected to the power grid illumination is achieved by incandescent or flourescent lamps while the remote villages use kerosene lamps. Even electrified households use kerosene or candles for the periods of powercuts. By and large majority of the households in developing countries are poorly lit. The desirable features of good light source are - high efficiency, long life, good colour, compact form and immediate lighting. Table 7 summarises the light requirements for different activities. Table 8 gives the characteristics of light from lamps burning different fuels. The important components are the fuel, lamp, the room size and colour of the walls. The lighting norm recommended by ABE is 30 kcal per capita per day. It is more appropriate to express this norm as per household per day as lighting is more related to type of the dwelling. Some relevant units, dimensions and definitions are given below.

Table 7 : Illumination Requirement for Interiors

	Location	Illumination (Lux)
1.	Dwellings	200
	Kitchen	150
	Study	
2.	Schools	
	Class room	150
	Lecture theatre	150 to 200
	Study hall	150 to 200
	Laboratory	150 to 300
3.	Offices	150
	General	300
	Drawing	50 to 150
	Enquiry	
4.	Hospitals	
	General wards	150
	Pathological laboratory	200 to 300
5.	Libraries	
	Stack room	70 to 150
	Reading room	150 to 300
	Counter area	200 to 300
	Catalogue room	150 to 200

Source : Indian Standard Code of Practice IS : (2440 - 1975

Table 8A : Characterisitcs of Different Lamps

Light Source	Light Output (Lumens)	Fuel Consumption (g/hr)	Power Rating (Watts)	Efficacy (Lum/W)	Efficiency (%)	Initial Cost (Rs)	Running Cost (Rs)	Light Cost Lumens/Re/day running cost only)
Electric Bulb (25 W)	252.52	25W	25.0	10.1	2.6	4.50	0.018	2805.0
Chirag (Ker)	20.93	6.28	81.1	0.258	0.065	10.00	0.016	261.6
Hurricane (Ker)	68.7	14.0	181.0	0.38	0.098	35.00	0.04	343.5
Organ (Ker)	98.5	19.2	248.0	0.397	0.10	30.00	0.06	328.3
Petromax (Ker)	1303	72.92	1044.0	1.25	0.239	250.00	0.19	1371.0
Mayadeep (Ker)	573	52.71	681.0	0.84	0.217	375.00	0.17	674.1
Noorie (Ker)	245	34.0	439.3	0.56	0.143	75.00	0.10	490.0
Petromax (LPG)	1005	80.8	946.0	1.06	0.22	300.00	2.06	97.5
Noorie (Alcohol)	212	64.66	506.0	0.42	0.108	75.00	0.20	213.0

Notes : (1) Calorfic value of LPG = 11.16 kcal/g
(2) Calorific value of kerosene = 12.92 Kwhr/kg
(3) Calorific value of Ethanol (95%) = 7.84 Kwhr/kg
(4) Cost of electricity = Rs. 0.75 Kwhr
(5) Cost of kerosene = Rs. 2.30/l
(6) Cost of ethanol = Rs. 2.50/l (assumed)
(7) All lanterns to run for 5 hours/day

Source : Rajvanshi (1987)

Table 8B : Characteristics of Different Lamps

S.No.	Lamp	Power Consumption (Watts)	Luminous efficacy (lm/W)		Colour rendering index	Average life (hours)
			Lamp	Lamp + ballast		
1.	Tungsten Incandescent	25 - 1000	9 - 13	-	100	1000
2.	Tungsten Halogen	1000	22	-	100	2000
3.	Flourescent					
	i) Cool Daylight	TL 20/40/65 TLD 28/36/58	49 - 62 54 - 69	32 - 50 34 - 54	77	5000
	ii) White	TL 20/40 TLD 18/36	58 - 69 64 - 77	38 - 54 41 - 58	65	5000
4.	Compact Flourescent	9	67	46	85	5000
5.	Blended Lamp	160/250	18 - 21	-	50	5000
6.	High Pressure Mercury Vapour	80 - 1000	44 - 57	38 - 54	45	5000
7.	High Pressure Sodium Vapour	150/250/400	90 - 118	79 - 107	25	> 12000
8.	Low Pressure Sodium Vapour	35	125	91	-	> 12000
9.	Metal Halide*	250 - 2000	68 - 95	63 - 90	70	- 7000

* Not available in India

Source : Gadgil etal (1987)

Units, Dimensions and Definitions

a) Inverse square Law : If a body emits energy E, then the intensity of illumination I at a distance d from the source is given by :

$$I = \frac{E}{4\pi d^2}$$

This equation is valid within 1/2 a percent when d is at least five times the maximum dimension of the source.

b) Units of Illumination : The S I unit of luminous intensity is candela. One candela is defined as the illumination of 1/600,00 m^2 of projected area of a black body radiator operating at the temperature of 2045 °K.

Energy per unit area is termed as flux and is normally expressed in Lux. This quantity is directly measured by a Luxmeter. Hence,

$$\text{Lux} = \text{Lumens}/m^2$$

$$1 \text{ lumen} = 2.576 \times 10^{-3} \text{ watt}$$

$$1 \text{ candela} = 12.57 \text{ lumens}$$

c) Illumination Efficiency (efficacy) of Light Source : The lamp efficiency is expressed in lumens per watt (lum/W) and is called lamp efficacy.

2.2 Agriculture :

Characteristics of hill agriculture are different from that of plains due to very different agro-climatic conditions. The enduses are

- land preparation
- fertiliser/manure
- irrigation
- harvesting
- post harvesting

We consider here only irrigation as there are alternative energy options for pumping water.

Irrigation :

Agricultural conditions in hill areas can be considerably improved by efficient water management and soil conservation. The traditional sources of irrigation in hilly regions are perennial streams and tanks. The irrigation requirements and technology involved would differ not only from site to site depending upon terrain and water table but would also differ for crops, orchards, nursery, horticulture etc. Hydrams, windmills, diesel engines or electrical pumpsets can be considered depending upon the suitability of technology and availability of potential (windspeed or water drop). The seasonwise and cropwise irrigation requirements are given in Table 9 For any technology for pumping the basic need is matching between pumping of water and water needs of agriculture

Table 9 : Irrigation requirements of Crops

Crops S.No.	Kharif	Rabi	Hot	Long Duration Crops	Avg. Daily Water Requirment (lit/hectare)
1.	Moong, Soyabeen, Castor Sesamum	Rapseed, Salflower Gram, Soyabeen, Cumith (Jira)	-	Tobacco	47520
2.	-	Sunflower, Gwar, (Hybrid), Peas	-	-	64800
3.	Jawar (Hy), Bajra (Hy), Maize (Hy), Groundnut, Vegetables	Wheat, Onion	-	Tur (Arhar), Cotton (Hy), Cotton (Hy), Tobacco (Rutia)	84240
4.	Paddy	Vegetables, Potato	Bajra (Hy), Groundnut Vegetables	Sugarcane	101520

Source : Norms provided by KBL Agricultural Pumping Systems as these vary from crop to crop and also depend on soil quality.

2.3 Energy needs of Industries

Typically, the Khoya making industry at the household level, the flour mills at the village level and the fruit processing industry in a few areas would be the major energy consuming industr~~y~~ies. The energy needs of industry would be constant and industry specific. The level of industrialisation in hills is less compared to that in the planes and will remain so due to environmental considerations.

2.4 Energy Systems in Commercial and Service Sectors :

The different enduses are :

- street lighting
- lighting in offices and restaurants
- space heating in offices and restaurants
- cooking in restaurants
- transport
- pumping of drinking water
- energy needs of tourism

The energy consumption for these enduses is by no means insignificant. The major feature that distinguishes these enduses from those discussed earlier is that the time, duration and amount of energy required would vary, also the planning for these amenities would depend on socio-economic considerations, hence the method of evaluation of energy options will be different.

3. ENERGY TECHNOLOGY SPECIFICATIONS

The traditional energy technologies in the hills are - biomass stoves for cooking, heating (water and space), and lighting, biomass/charcoal stoves for space heating, oil or kerosene lamps, animal powered agricultural technologies, watermills for milling, biomass combustion technologies for agro-industries and for horticulture. With the introduction of electricity and petroleum products their use in water pumping, transportation and other activities has replaced some of the traditional technologies. Though this shift has resulted in development at local level majority of the population still depends on biomass energy and animal power and this energy use pattern is likely to continue for a few more decades. The role of biomass used for energy in causing deforestation may be debatable but the impact of deforestation on availability of biomass for energy use is obvious. Hence, there is a need to conserve on the current use of biomass for energy purposes. From a national perspective it is essential to limit the use of fossil fuels. The use alternative energy resources to meet the increasing energy demand requires enviornmentally sound, financially viable and socially acceptable planning. In this section we describe the relevant energy technologies and their system configuration for different enduses.

3.1 Biomass based options

Biomass is defined as the living matter or its residues and therefore is a renewable resource. In the present context biomass refers to wood, grass, sugar crops, crop residues, food processing wastes, human and animal wastes. Biomass fuels meet the energy needs of majority of the households in developing countries and now they are being considered for meeting the energy needs of commercial applications also. The ecological stability of the hills depends on its biomass resources to a large extent, hence further use of biomass as an energy option has to be examined critically in the context of its scarcity. The production of biomass is a slow natural process and quite often the rate of generation is less than the rate of consumption which leads to progressive depletion of the resources. In the energy management of a hill district one of the strategies of foremost importance would be to keep the overall rate of consumption of biomass from forests or grasslands within the sustainable rate.

Therefore, though a number of technology options are discussed, their application should depend on the local biomass situation.

Improved Biomass Stoves :

Figure 1 shows a minimum system to be studied while examining the biomass stoves. It has been shown that the present biomass cooking stoves are inefficient and

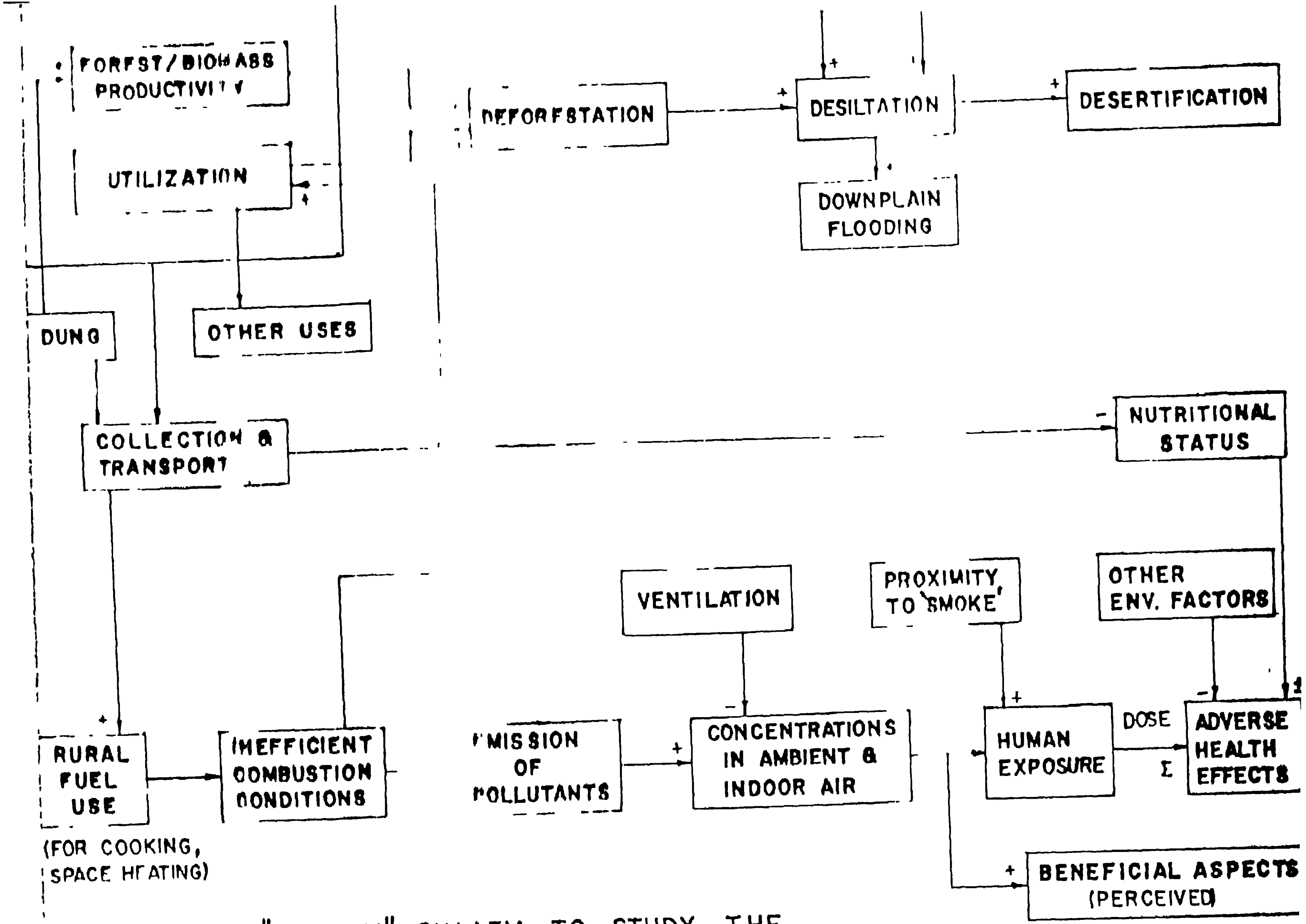


FIGURE I· THE "MINIMUM" SYSTEM TO STUDY THE BIOMASS-COMBUSTION BASED RURAL COOKING ENERGY SYSTEM

THE SIGNS AT THE ARROWHEADS REPRESENTS UPWARD (+) OR DOWNWARD (−) CHANGES IN THE TARGET BOX FOR AN INCREASE IN THE SOURCE BOX polluting. But in the hills if the same stoves are used for space heating, then their combined efficiency is what matters. There is unfortunately no data on this though there is data on fuel consumption in the hills.

There are a number of improved models of fuelwood stoves for cooking. Figure 2 shows some of these models.

As one is only aiming at conservation of energy it is important to ensure that firstly the fuel savings should be substantial under actual field conditions and secondly, the cooking needs of the hill people should be met.

Improved Space Heaters :

Space heating is traditionally achieved by cooking stoves along with water heating (Figure 3). There are also separate coal based space heaters (Bukharies) in some hilly areas (Figure 4). These typically consume 8 kg coal, 2 kg wood and 200 cc kerosene in 6 to 8 hours as a single charge. A space heating cum cooking system similar to one in China (Kang) can be an option or improved space heaters based on wood or coal can also be considered. Some of the improved space heaters (bukharies) based on coal being developed by TERI are shown in Figure 4. If the space heating needs are met by a multipurpose biomass stove, introduction of an improved space heater will probably result in more overall fuel consumption.

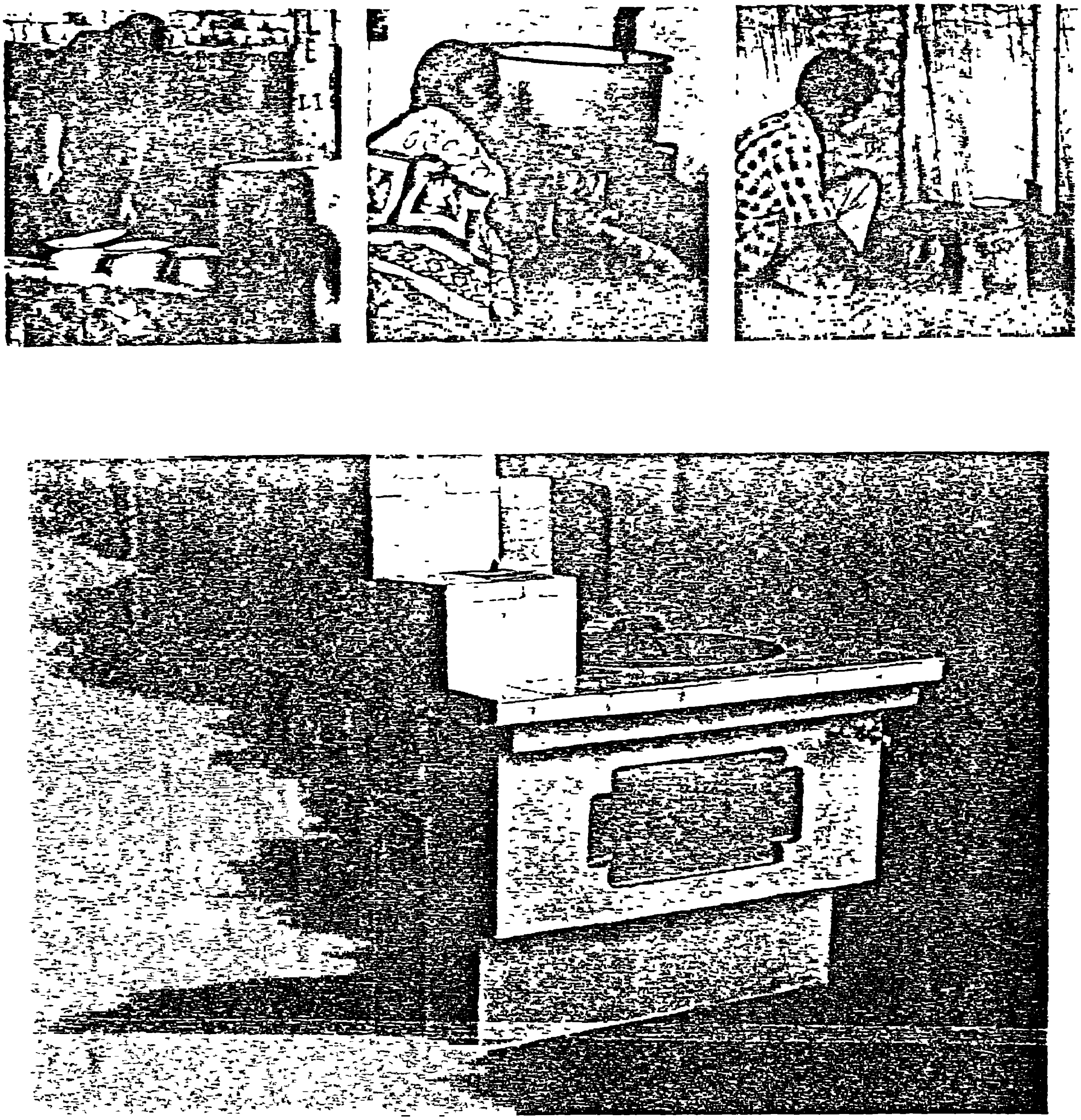
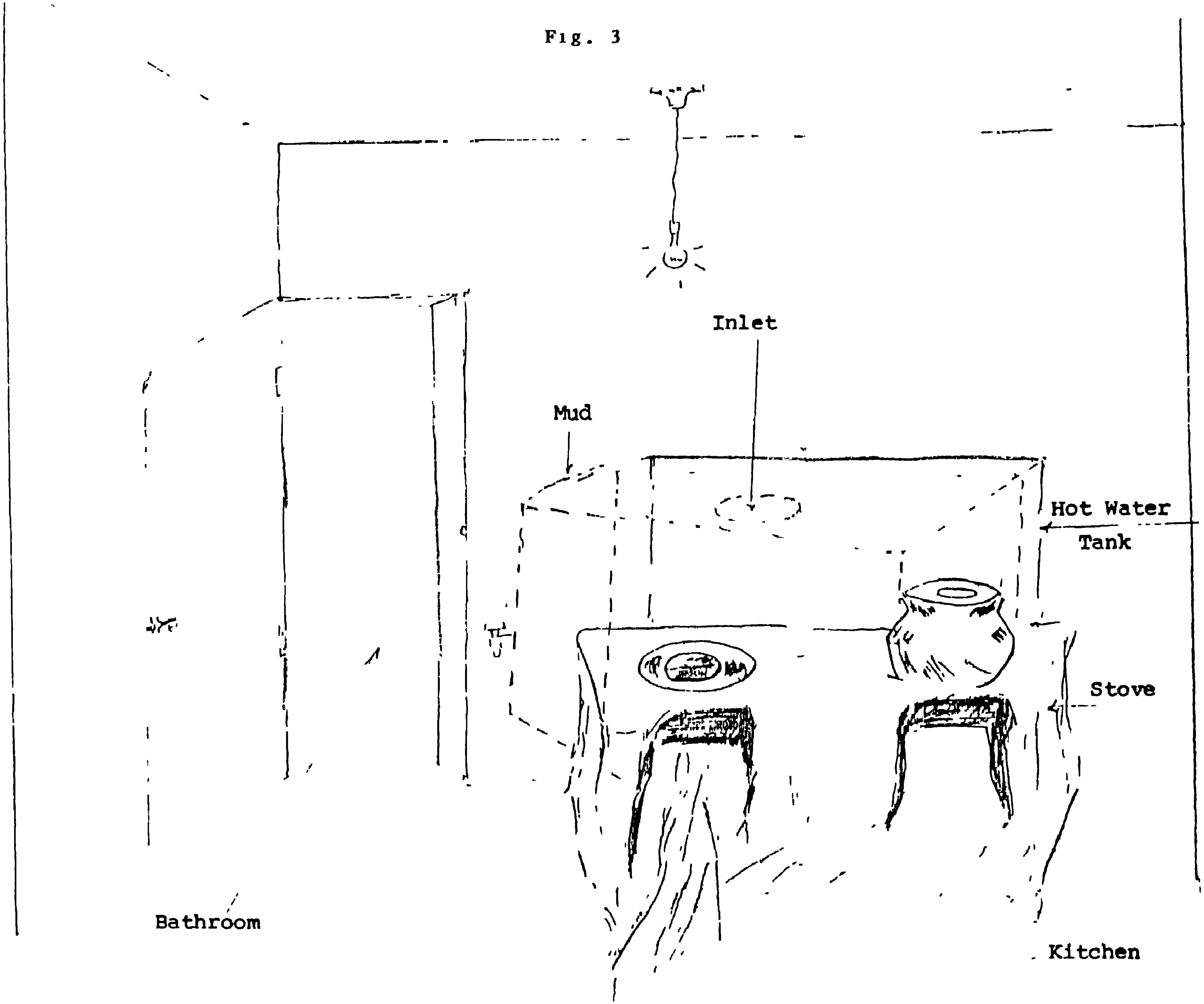


Fig.2 Improved Stoves

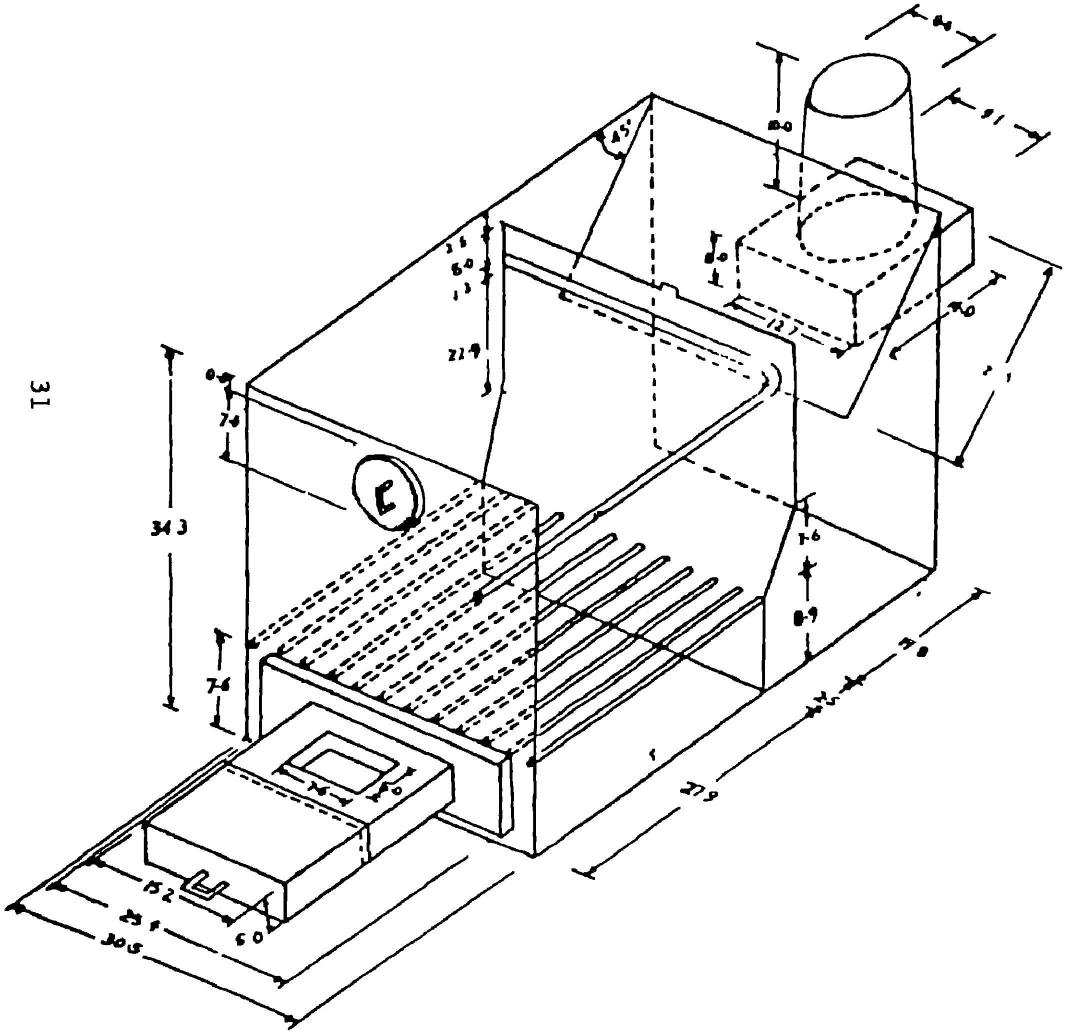
Fig. 3



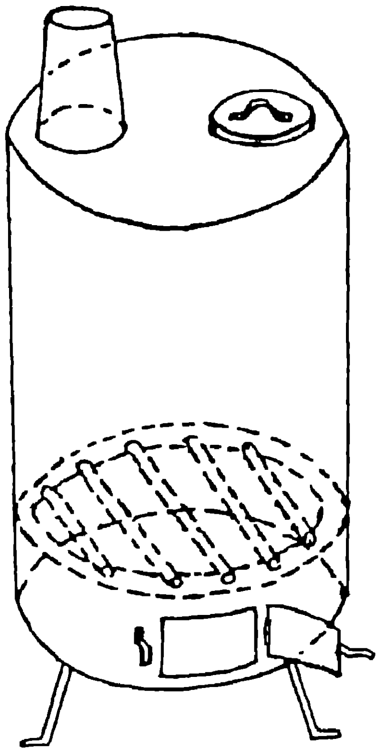
Combination of Water heating, cooking and space heating

Fig. 4

BUKHARI PROTOTYPE MARK II



4 a ALL DIMENSIONS IN CM



TRADITIONAL BUKHARI
HEIGHT = 40 cm
DIAMETER = 28.5 cm

4 b

Source : Gadgil (1983)

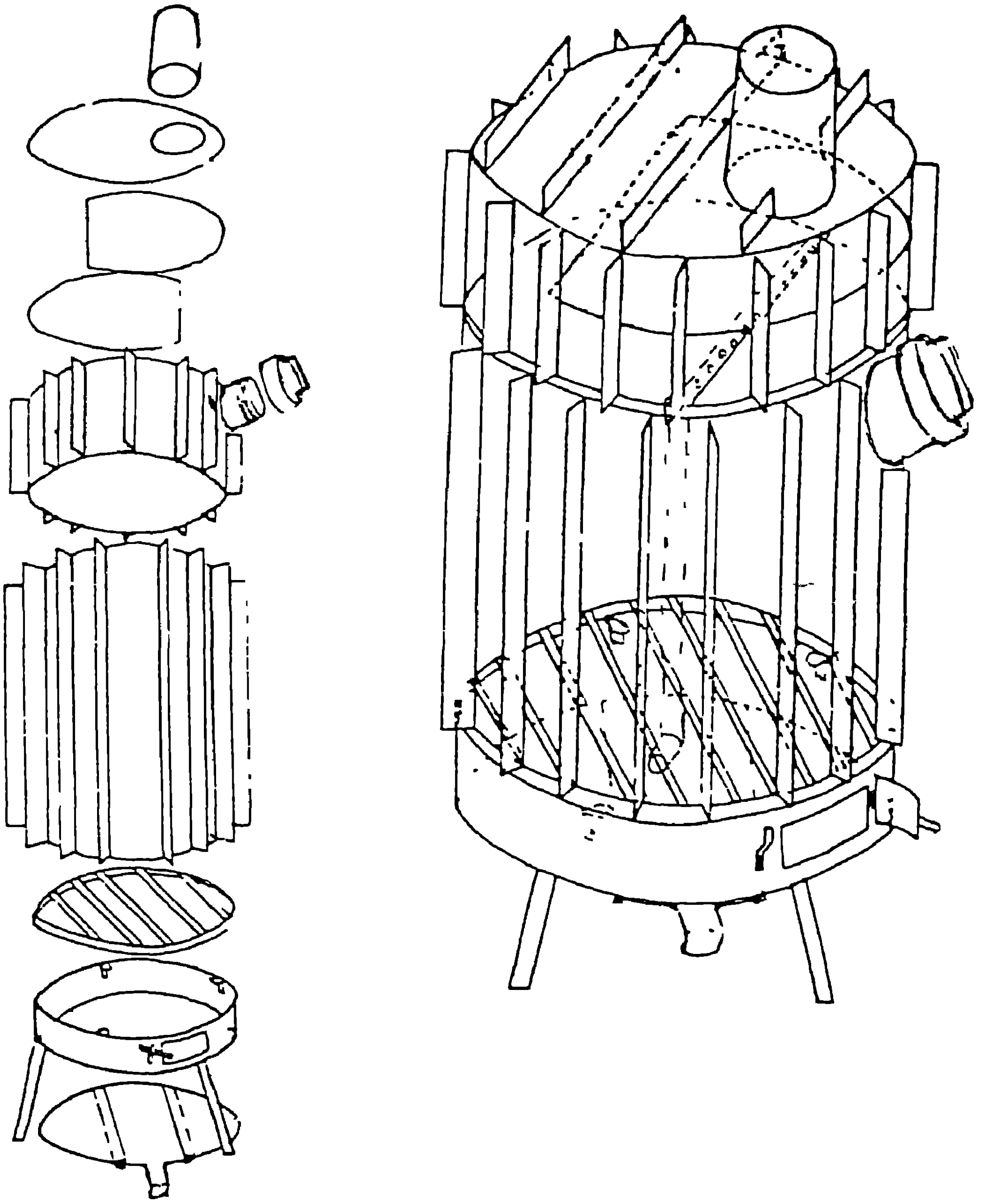


Fig. 4c

Biogas Technology

Biogas is a mixture of combustible gases produced due to the microbiological degradation of organic material in an anaerobic environment. The anaerobic digestion of biomass results in biogas consisting of methane (50-70%) carbon dioxide (25-45%) and traces of hydrogen, nitrogen and hydrogen sulphide. The simplified chemical reaction of the process would be

$$\text{Biomass} \xrightarrow[\text{micro organisms}]{\text{anaerobic}} CH_4 + CO_2 + H_2S$$

with traces of H_2 and N_2

The digestion process occurs over a wide range of temperatures subject to the condition that an effective temperature range is established. The optimum temperature for the process is considered to be approximately 35 °C.

The unit where the organic waste materials are digested is called the Biogas Plant. A typical plant has the following parts

- a tank for mixing the materials with water (inlet tank).
- an underground airtight tank called digester where the slurry is let to remain for a few days (30-50 days).
- a gas holder or gas space at the top of the digester for collecting the gas product.

- an outlet tank to which the sludge flows out from the digester and
- gas pipes for piping biogas from the gasholder to the kitchen/lighting or other points of use.

There are a number of models of Biogas plants but the two well known models in India are the KVIC type and the fixed dome type. In the KVIC model gas is collected in gas holder while in fixed dome type it is collected in the dome. The fixed dome type biogas plant is also cheaper to construct and is more suitable for wastes like crop residues, water hyacinth, cattle dung and night soil, while KVIC design is suited only for cattle dung and night soil. The different biogas designs are shown in Figure 5.

Most of the fixed dome plants currently installed in India are designed with a retention period of 50 days. Table 10 illustrates typical gas production capacity.

Table 10

Gas Production Capacity m3/day	No of Cattle	Sufficient for Cooking (family size)
2	4 - 5	5 - 6
3	6 - 8	6 - 10
4	9 - 11	10 - 15
6	12 - 15	15 - 20

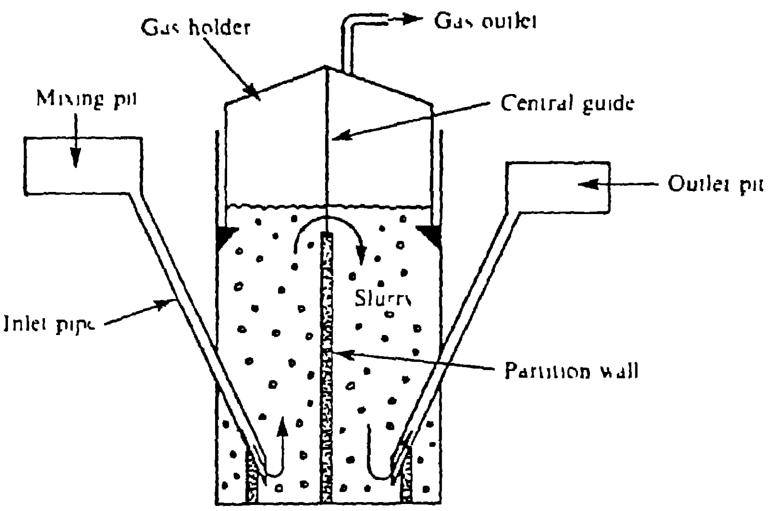


Figure 12-6 Floating cover (Indian) digester

Fig. 5a Floating Type Biogas Plant

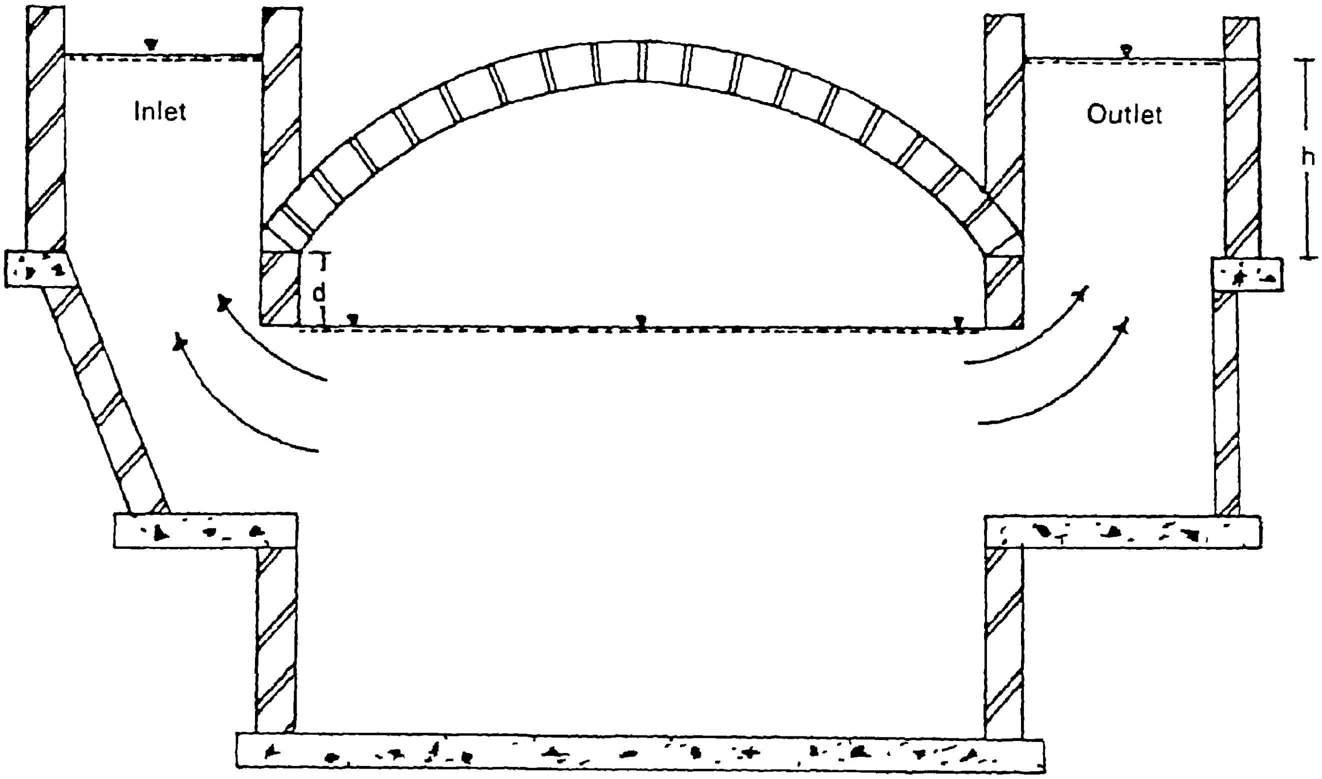


Fig. 5b Fixed Dome Type Biogas Plant

Table **11** : Annual human and animal excrement and their collection coefficients

	Excrement per head (kg)	Proportion of dry weight (%)	Collection coefficient (%)
Human excrement	90	30	70
Human urine	700	10	70
Cow dung	7 300	17	70
Cow urine	3 650	6	70
Mule and horse dung	5 475	24	70
Mule and horse urine	1 825	10	70
Pig dung	548	18	70
Pig urine	1 095	4	70
Sheep dung	548	35	70
Sheep urine	274	13	70

Table 12: production of gas from biomass

Variety	Amount of gas produced m^3 per kg of dry weight)	Methane content (%)
Rice straw	0.20 - 0.26	57 - 62
Wheat straw	0.29 - 0.35	58 - 68
Corn stalks	0.25 - 0.30	62 - 68
Human waste	0.20 - 0.31	50
Cow dung	0.13 - 0.26	54 - 61
Horse dung	0.20 - 0.30	60
Pig dung	0.22 - 0.30	55 - 62
Sheep dung	0.20 - 0.25	N.A.
Tree leaves	0.21 - 0.29	56
Green weeds	0.21 - 0.25	70
Water hyacinth	0.16 - 0.31	58 - 68
Water peanuts	0.20 - 0.25	N.A.
Water lettuce	0.20 - 0.25	N.A.

Tables 11 and 12 summarize typical dung and gas production data. While considering biogas plants for hilly areas the low ambient temperatures act as a constraint. Due to the low ambient temperatures a biogas plant in the hills will produce lower gas than a plant in a more temperate zone. In addition there will be further decrease in gas production in winter leading to complete stoppage at about 5°C.

There can be three types of solutions -

i) To increase the slurry temperature: The attempts to increase the slurry temperature using green house or using cost-effective shallow solar ponds have not resulted in any significant rise in slurry temperature. In case of Janata plants a temperature increase of about 5°C is observed by using green house for heating. For floating dome type further Calculations based on heat losses have shown that heating of slurry using part of gas produced would result in a negative energy balance for digester temperatures greater than 20°C. Another option could be to have a separate gas storage space so that only the digester can be heated. But actual experiences with such experiments is very limited.

ii) To increase the retention time: The relationship between gas production rate and retention time at different slurry temperatures shows that an increase in retention time above 50 days will not increase the gas production significantly for temperatures above 20°C.

Moreover, this option would increase the cost of the biogas plant. In China, most plants have a retention period of about 100 days.

iii) Use of insulation to reduce losses: This is an expensive option requiring a solid insulation for under the ground part of the biogas plant and can be effective along with external heating. Thus it can be said that more technology innovations are required before adopting biogas plants on a large scale.

Some useful information

Optimum temperature = 30 - 35 ^{o}C

Optimum PH of the slurry = 7.5 - 8.5

1 kg wet dung = 0.0425 m^3 biogas
(for RT = 50 - 60 days)

Human waste from 1 person + 1 litre water = .0286 m^3

Calorific value (60% methane) = 5128 kcal/m^3

Gas Utilization

for cooking = 0.23 m^3/person - day

lighting => 1000 candle power mantle = 0.13 m^3/hr

Specific Fuel Consumption :

2" burner = 0.033 m^3/hr

4" burner = 0.047 m^3/hr

Diesel Engine = (80% biogas 20% diesel)
= 0.43 m^3/hP-hr

1000 candle power (=60 W) mantle = 0.13 m^3/hr

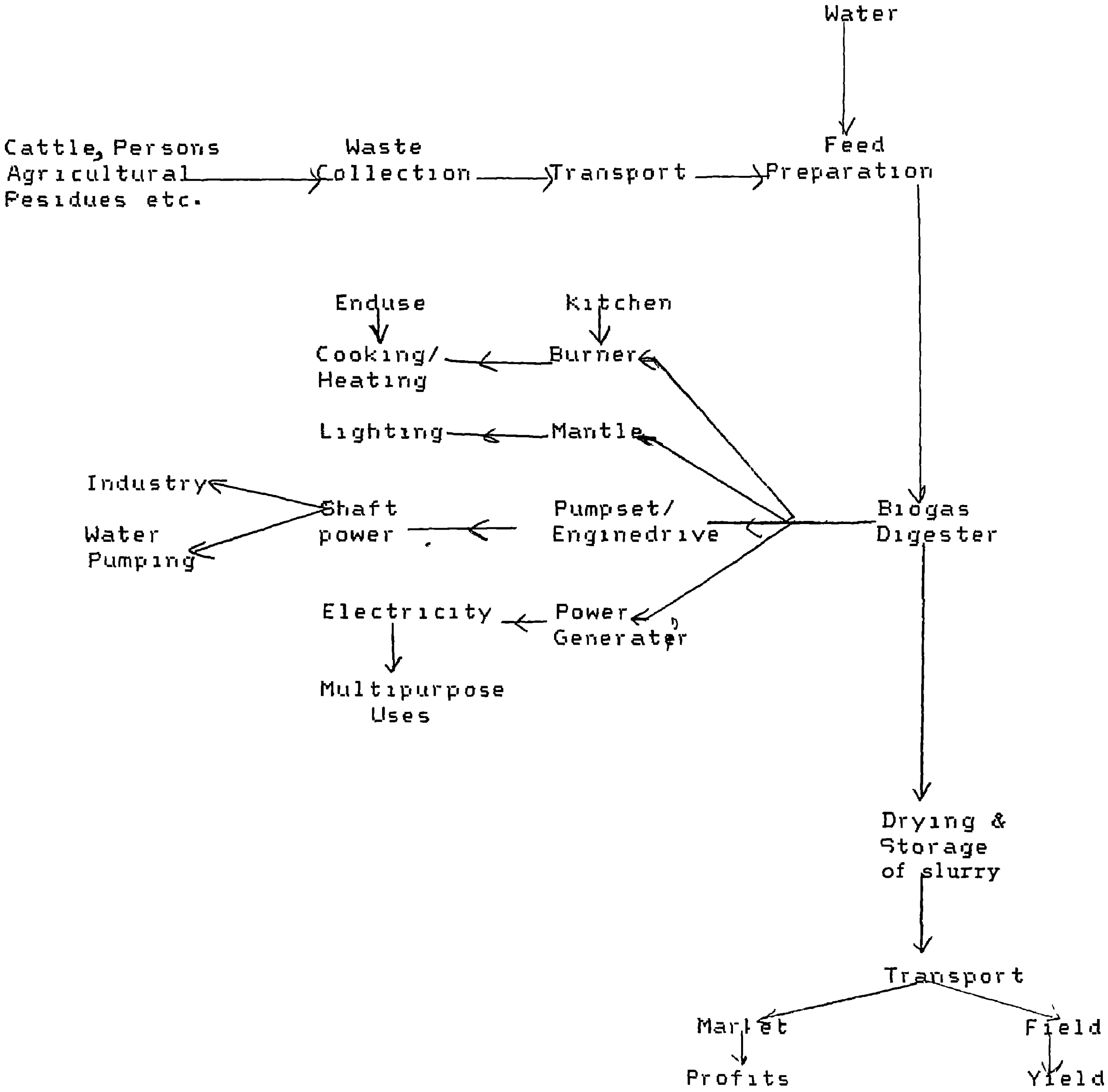


Fig6 : Biogas Technology - A Complete System

Generation of electricity with biogas -diesel = 0.7 m^3/kW.hr

One thousand kg (dry) biogas manure contains 17 kg N_2 (equivalent to 37 kg Urea), 15 kg P_2O_5 (equivalent to 94 kg Super Phosphate) and 10 kg K_2O_5 (equivalent to 17 kg Muriate of potash).

Gasifier

Utilization of biomass as a source of energy for shaft power generation or for generation of electricity calls for its conversion to a more convenient form, liquid or gaseous before using it in existing devices.

A gasifier converts a solid fuel by a series of thermochemical processes like drying, pyrolysis, oxidation and reduction, to a gaseous fuel called producer gas. If atmospheric air is used as the gasification agent, which is the normal practice, the producer gas consists mainly of carbon monoxide, Hydrogen, Nitrogen. A typical composition of the gas obtained from wood gasification is as follows :

Carbon monoxide	18 - 22%
Hydrogen	13 - 19%
Methane	1 - 5%
Heavier hydrocarbons	0.2 - 0.4%
Carbon dioxide	9 - 12%
Nitrogen	45 - 55%
Water vapour	4%

The calorific value of this gas is about 1000 - 1200 $kcal/Nm^3$.

The various biomass fuels that can be used in the gasifiers are

- Wood chips from logs and slabs
- Wood waste from Timber harvesting, saw mill operations etc.
- Crop residues like wheat straw and cotton stalks
- Rice husk
- Dungcakes

The above list is not exhaustive and in fact any carbonaceous matter can be gasified in principle. However, it is found that fuels with a high ash content are not easily gasified and pose a major technical challenge at present. Also, some sort of pretreatment like drying, densification (briquetting) of biomass etc. is usually needed before use in the gasifier.

Gasifiers can be broadly divided into two categories - fixed bed and fluidized bed gasifiers. The technology of fluidized bed gasifiers is relatively new and complicated, and is not to be justified for small systems. The advantage of this process is that the gasifier can be operated on a wide range of biomass fuels and in particular those fuels with high ash and moisture contents. Fixed bed gasifiers are classified in three types - updraft, downdraft and cross draft.

These are shown in Figure 7. These are batch-type units which can be operated for a few hours with each loading of the fuel. They consist mainly of i) a fuel hopper ii) a fire box or hearth where combustion takes place iii) a grate for ash removal iv) an ash pit and v) air inlet and gas outlet.

As shown in Figure 7, the three types of gasifiers differ by the relative positions of the air and gas ports. In the updraft gas producer, air is induced under the grate to provide the oxygen for partial combustion of carbon immediately above the grate. The hot gaseous combustion products proceed upward through a reduction zone of incandescent charcoal where heat is consumed to gasify the carbon and produce hydrogen. Then product gases transfer heat to the raw fuel, first pyrolizing it and then drying it. The gas exits above the upper zones at a location shown in Figure 7 or at a side port near the top of the gas producer. It will have a high vapor content of condensable tars and water if the fuel is raw biomass. Thus, this type of gas producer is best suited for dry, low volatile fuels such as charcoal and coke. Steam is alternatively blown with the air entering the gasifier to increase the hydrogen content and decrease the nitrogen content of the product gas to produce a medium-CV gas usually known as Water or Town gas.

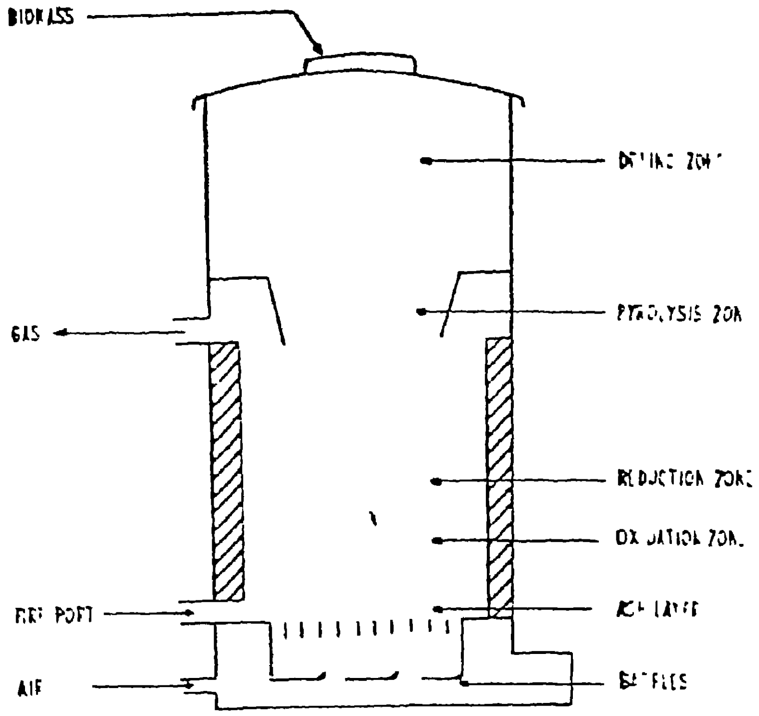


Fig. 7a Updraft Gasifier

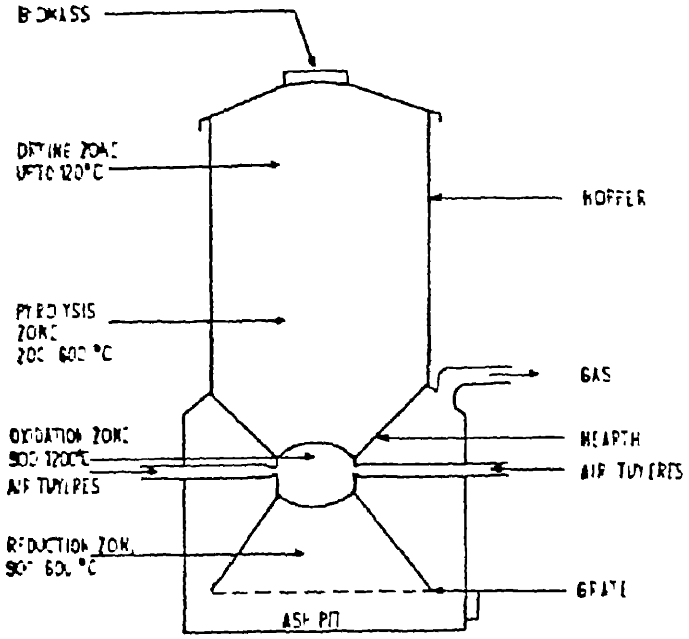
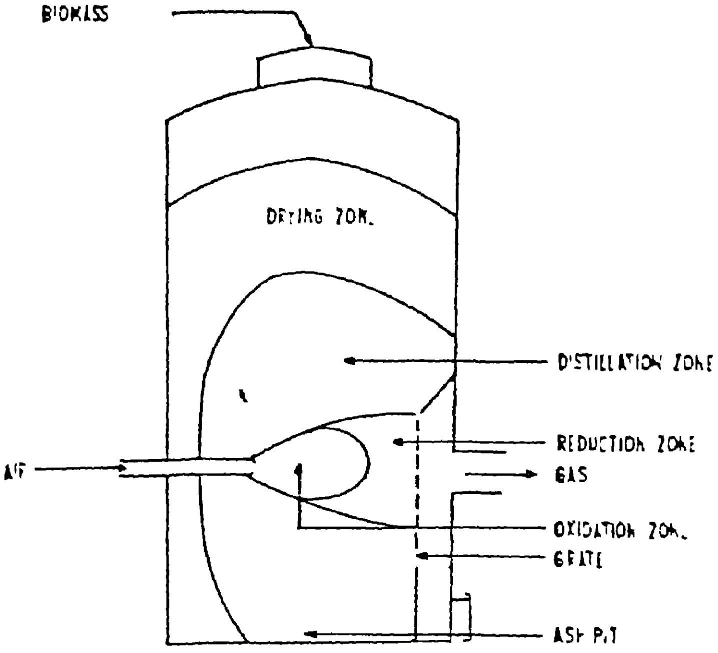
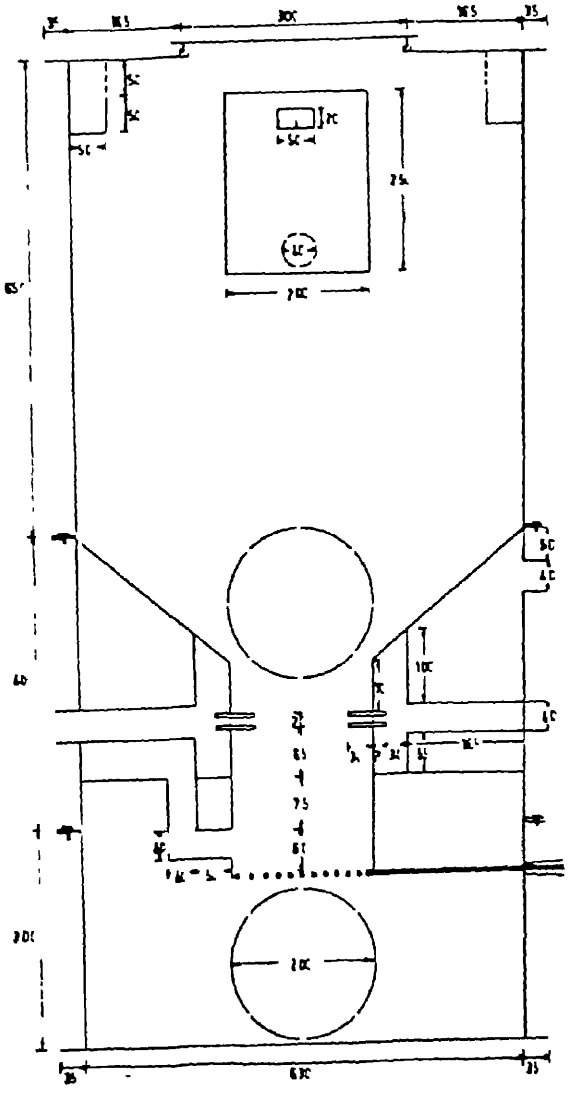


Fig. 7b Downdraft Gasifier

Fig. 7c Crossdraft Gasifier



BIO-MASS GASIFIER [illegible]



In the downdraft gasifier, air enters through radial tuyeres near the top of the fire box. The partial combustion takes place in the zone in front of the tuyere openings. The heat generated pyrolizes the fuel immediately above and the hot gases proceed downward through the fire box constriction. The throat aids in the cracking of the most of the unburned pyrolysis gases into gaseous hydrocarbons that do not condense under temperatures and pressures at or near ambient conditions. The hot gas port is normally near the top of the fire box.

Air enters the crossdraft gasifier through a water cooled nozzle mounted on one side of the fire box. The gas is produced in horizontal zones in front of the nozzle and passes through a vertical grate into the hot gas port on the opposite side.

In Figure 7, the air for partial combustion of the fuel is either induced by the vacuum in the intake manifold to an internal combustion engine which is connected by piping to the hot gas port of the gas producer or forced into the air port by a blower. The rate at which gas is produced is almost wholly dependent upon the air flow rate. Thus, if the gas producer is connected to an engine, the amount of gaseous fuel produced is self-regulated by the power demand at the engine crankshaft which is directly reflected in the vacuum in the intake manifold.

In all the three types of gasifiers described above, the raw producer gas generated contains varying amounts of moisture, dust, char particles and tar. All these impurities are detrimental to the operation of IC engines and hence the gas has to be cleaned extensively before admitting into the engine. Of these three types, the downdraft gasifier produces gas with low tar contents, and is generally preferred for use in conjunction with engine operation.

Figure 8 illustrates the other components to be considered while planning for the use of gasifiers. Figures 9 and 10 illustrate a typical system configuration for power generation and shaft power respectively.

This technology is still under development. In a few locations where biomass is a real waste, it can be tried. Typical resource requirements are given in Table 13.

Table 13

Enduse	Extent of use hrs/year	System capacity	Fuel Requirement tonnes/yr
Irrigation	1000	3.5 kW engine pumpset	3.5
Power Generation	4000	1 MW generation capacity	4000

Source : Jain (1987)

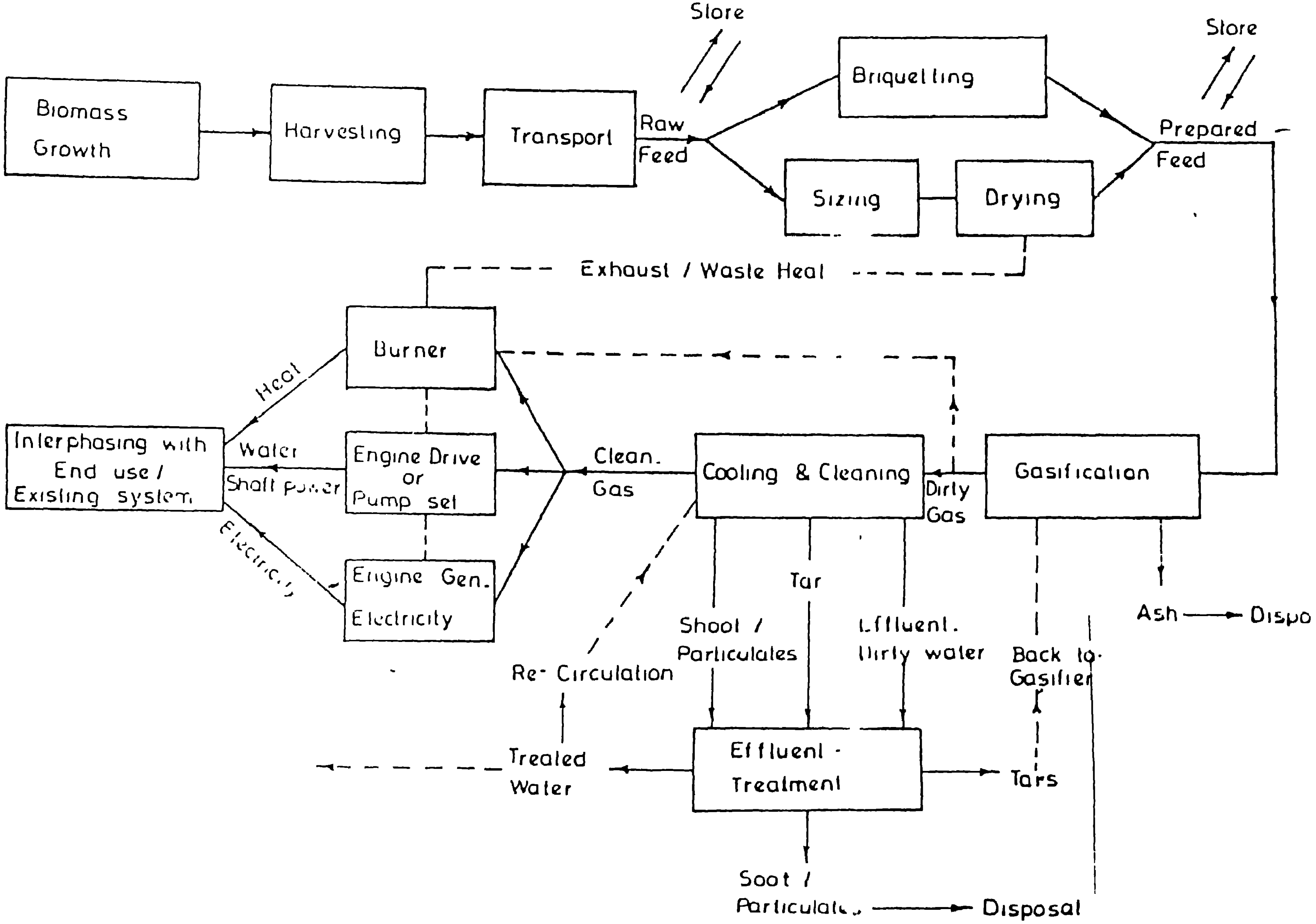
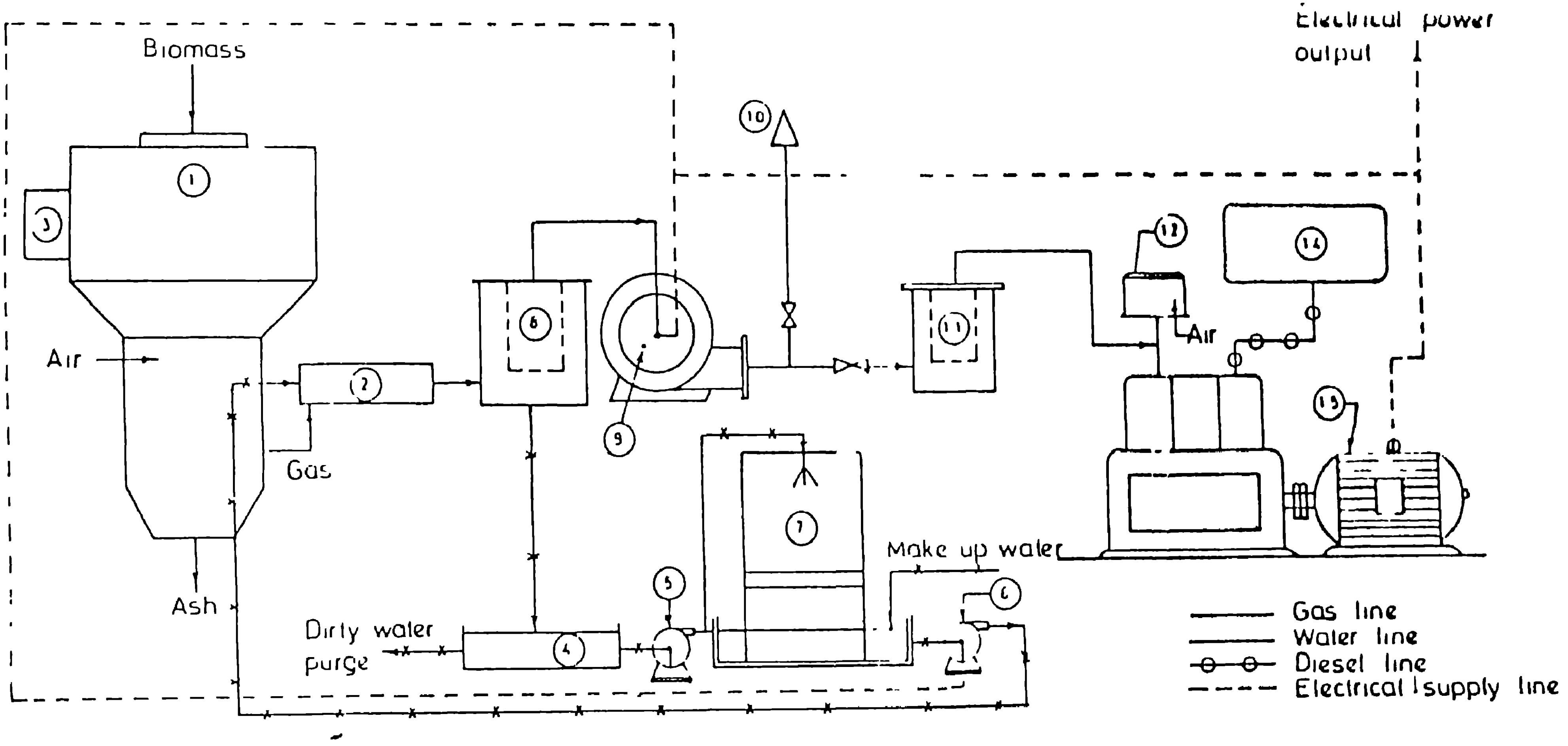


Fig. 8 Biomass Gasification-Systems Approach

Source : Jain (1987)



LEGEND

1 Gasifier
2 Gas Cooler-Cleaner
3 Vibrator
4 Hot Dirty Water Sump
5 Cooling Tower Sump
6. Water Recirculation Pump
7. Cooling Tower
8. Separator Box with Filter
9. Blower
10. Flare Burner
11. Security Filter
12. Air Filter
13. C.I. Engine
14. Diesel Supply Tank
15. Electrical Generator

Fig. 9 Schematic diagram for a typical gasifier-engine system for electrical power generation (employed in India)

Source: Jain (1987)

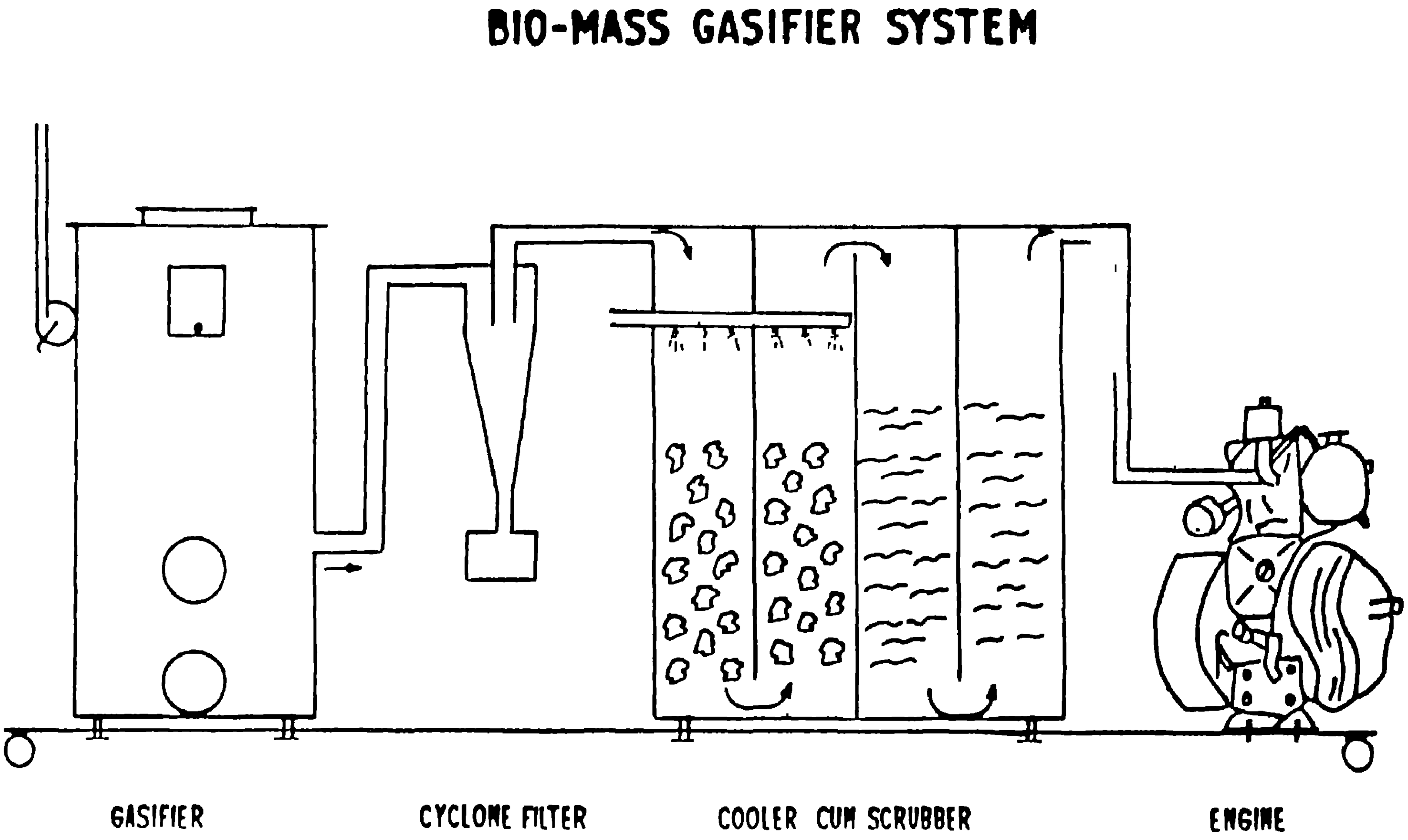


Fig. 10 Biomass Gasifier Water pumping based on gasifier

Charcoal Kilns and Briquetting

Charcoal is a more convenient fuel and is traditionally preferred to wood for domestic as well as industrial use. Charcoal is still produced by traditional means where 1 tonne charcoal is produced from 8.6 tonnes of air dry wood. The details of this technology are discussed elsewhere in the manual.

Densification of the biomass by briquetting results in a fuel much easier to handle, with a high heating value, long burning time and in some processes can also give almost smokeless fuel.

The techniques available for making briquetted fuel can be broadly categorized into two groups:

1. Briquetting after pyrolysis of biomass - This process involves conversion of agricultural wastes into char and then briquetting this char with the help of a binder. The fuel thus obtained is almost smokeless and hence is useful for domestic purposes.

There are both small and high capacity plants available for briquetting by this process. The commercially used plants have a capacity of about 4 tonnes/day whereas the capacity of family and community level plants varies from 5 kg of briquettes/8 hours to 2 tonnes/24 hours.

Though this process gives clean fuel, it is quite wasteful due to high energy input required for pyrolysis. In fact it is seen that if used in cooking, at the existing efficiency of the chulhas, the additional energy input required in this process is more than the useful energy output.

2. Briquetting by direct compaction : In this category there are two kinds of processes in use.

(i) Briquetting using binders - In this process, pressures of 500 - 1000 kg/cm^2 are used with binders like molasses, ligna-sulfonate etc. The higher capacity machines are electrically operated, but there are smaller capacity machines available which can be either run manually or by using electric power giving an output of 0.1 - 0.4 tonnes/hour.

The main problem with the fuel briquetted by this process is its highly smoky nature (due to the binders), which renders it unfit for domestic purposes.

(ii) Binderless briquetting - This technique involves the use of high pressure (1200 - 1400 kg/cm^2) to densify the biomass and hence doing away with the binder. Thus the fuel obtained is almost smokeless and has very little ash content.

At present, there are machines available for this process with a capacity range of 100 kg/hr - 3000 kg/hr and with a power requirement of 22 - 110 kW.

The suitability of any of these techniques is dependent on the quantum of crop residue available in a region as also the enduse of the briquettes.

3.4 Solar Technologies

In principle, solar energy could supply all the energy needs of the world on a continuing basis. Unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Also, it is freely available in adequate quantities in almost all parts of the world.

However, there are many problems associated with the use of direct solar energy. The main problem is that it is a dilute source of energy, with a maximum flux density of $1kw/m^2$, which is a low value for technological utilization. Consequently, large collecting areas are required in many applications, resulting in excessive costs. A second problem is that its availability varies widely with time. This variation occurs daily because of the day-night cycle and also seasonally because of the earth's orbit around the Sun. In addition, variations occur at a specific location because of local weather conditions. Hence the energy collected when the Sun is shining must be stored for use during periods when it is not available The need for storages adds significantly to the cost of any system Thus, the real challenge in utilizing solar energy is of an economic nature One has to strive for the development of cheaper methods of collection and storage so that the large investments initially required are reduced. The direct means of Solar energy utilization include thermal and photovoltaic conversion.

Solar collectors and storage subsystems are two main components in various solar systems and hence will be described in brief.

(i) Conventional flat plate collector

The flat plate collector shown in Fig. 11 is simple in design, has no moving parts and requires little maintenance. It is quite effective for temperature levels below 100^{o}C and hence is mainly used for water heating. It consists of i) a cover system (usually made of glass plates), ii) a blackened tube-and-plate configuration called the absorber, iii) a back insulation and iv) a casing. Cold water enters at the bottom of the collector and the hot water leaves from the top. Solar radiation, after reflection and absorption through the cover system, is absorbed by the black plate, and transferred to the liquid flowing in the tubes. At the same time, heat is lost from the absorber to the surroundings by convection and radiation. The function of the cover system is to reduce these heat losses. The heat gained by water while passing through the collector can be expressed by the equation:

$$Q_u = F'A_c\left[(\tau\alpha)G - U_L(T_f - T_a)\right]$$

Where F' is a collector efficiency factor dependent on the material of the absorber, tube spacing etc.; A_c is the collector area, $(\tau\alpha)$ is the fraction of the

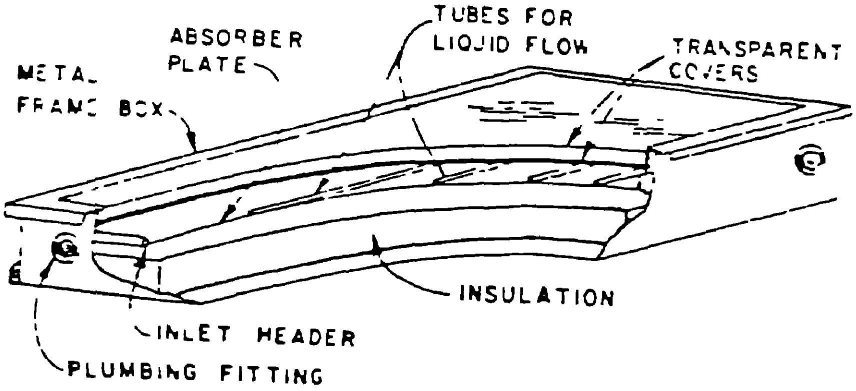

TUBES FOR LIQUID FLOW
ABSORBER PLATE
TRANSPARENT COVERS
METAL FRAME BOX
INSULATION
INLET HEADER
PLUMBING FITTING

Fig. 11

radiation transmitted by the cover system, G is the total radiation in the plane of the collector, U_L is the rate of heat loss from the absorber per unit area per unit temperature difference, T_f is the mean fluid temperature and T_a is the ambient temperature. The two most important parameters governing the collector performance are ($\tau\alpha$) and U_L. In hills the low ambient temperatures will be an additional constraint. For a collector with a single glass plate, ($\tau\alpha$) is high, but U_L is also high. U_L can be decreased by increasing the number of covers, but at the cost of decreased ($\tau\alpha$). One of the major endeavours of solar scientist has been to reduce u_L while keeping ($\tau\alpha$) at the highest possible value. Two methods of doing this are i) by means of a selective coating on the absorber and ii) by the use of honey combs or `cells' in the space between absorber and glass. An ordinary black paint can absorb a large fraction of light incident on it, but it also losses heat by re-radiating in large quantities. In technical words, it has a high absorptivitiy and high emissivity. A selective coating, on the other hand, has a high absorptivity, but also low emissitivity, resulting in a low value of U_L. Honey combs mainly perform the function of suppressing convection currents, again resulting in a lower value of U_L, that is by evacuating the space between the absorber and cover glass, but this is a technically difficult problem. Special types of collectors, called the `evacuated tubular collectors' are commercially available in developed countries.

Flat plate collectors available in India cost between Rs. 1,200 - Rs 2,000 per square meter, depending upon the materials used. An absorber plate with copper tubes and copper plate is most desirable as there are no corrosion problems involved and also copper is a good conductor of heat resulting in a higher value of F'. but copper collectors are more expensive. Efforts are on in many countries to develop cheaper flat plate collectors. use of plastics for cover system, absorber plate etc. can solve the problems of corrosion, cost etc., but the plastics (polymer) industry in India is not as developed as in the Western Countries and hence plastic collectors have not yet appeared on the Indian scene.

The relevant system for the hills is a Box type collector shown schematically in Fig. 12A. It consists of a closed shallow rectangular box, 5 to 10 cm deep, made from sheet metal. The box is contained in a housing which supports a glass cover and is insulated around the bottom and sides The box is filled with water in the morning, which heats up through the day and is withdrawn for use in the evening. An insulated flap on the top can be used to store the hot water for next day morning's use.

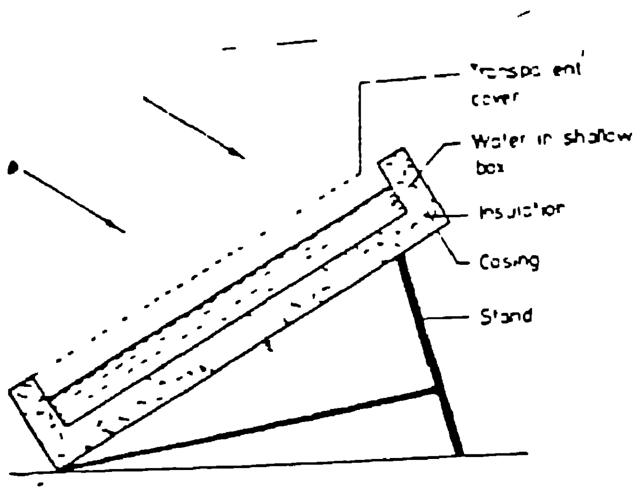


Fig. 12a

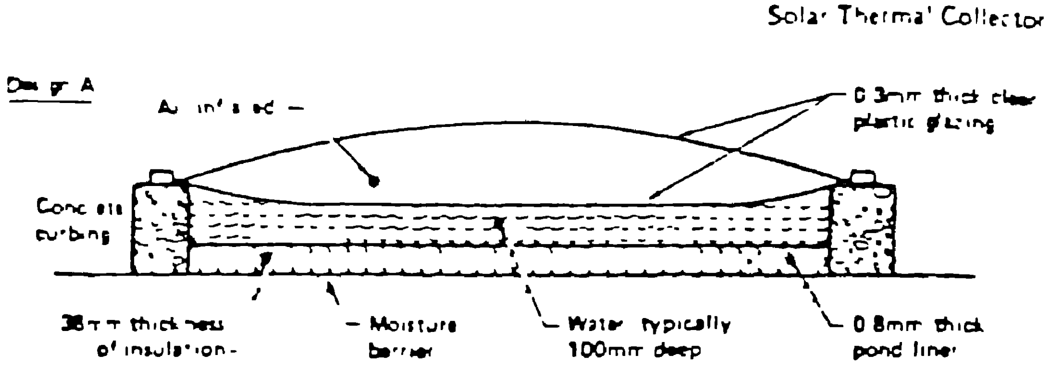


Fig. 12b

Shallow Solar Ponds : Figure 12B shows a diagram of the Shallow Solar Pond (SSP). It consists of a shallow body of water, typically 10 cm deep, contained between a bottom black plastic sheet and a top transparent plastic sheet. An additional thin, transparent plastic sheet can be provided on top to reduce the heat losses. The SSP's are necessarily horizontal and are installed either directly on the ground or with additional bottom insulation. The efficiency is somewhat lower than the box type collectors, because they receive lesser radiation than an inclined surface, but the major advantage of SSP's is their low initial cost (Rs. 300 - 400 per m^2).

3. Concentrating collectors

For achieving temperature higher than 100 °C, it is necessary to intensify the solar radiation received by the absorber. This is done by means of `focusing' or `concentrating' solar radiation onto the absorber subsystem. Unlike the flat plate collectors which utilize both the direct and diffuse radiation, concentrating collectors use only the direct component. Also, as the direction of sun rays keeps changing, it is necessary to `track' the sun in the case of concentrating collectors. From these considerations, concentrating collectors are more expensive to install and maintain.

The `aperture' of a concentrating collector is defined as the plane opening through which the solar radiation passes. The term `receiver' is normally used to denote the subsystem consisting of the absorber, cover and other accessories. The `concentration ratio' (C.R.) is the ratio of the effective area of the aperture to the surface area of the absorber. This ratio can be used as a measure for classifying concentrating collectors. A number of concentrating collector geometries are shown in Figure13. Figure13A shows a type which is basically a flat plate collector with adjustable mirrors at the edges to reflect radiation onto the absorber plane. It is simple in design and has a C.R. of a little above unity. The box type solar cookers usually have this feature. The compound parabolic collector (CPC) or Winston Collector shown in Fig. 13A consists of curved segments which are parts of two parabolas. The C.R. is moderate, ranging from 3 to 10. The main advantages of the CPC is that it requires only occasional tracking. Working temperatures upto 150°C can be attained in CPC systems. Figure 13C shows the sketch of a cylindrical parabolic collector in which the image is formed on the focal axis of the parabola. This type of collectors have C.R.'s between 10 and 30 and yield temperatures between 150 and 300°C.

In order to achieve higher concentration ratios and temperatures, it is necessary to have point focusing

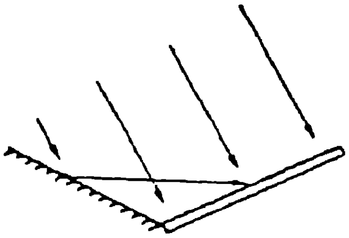


Fig. 13a

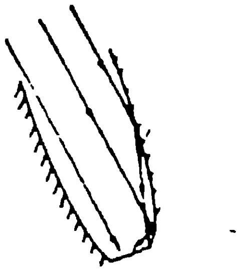


Fig. 13b

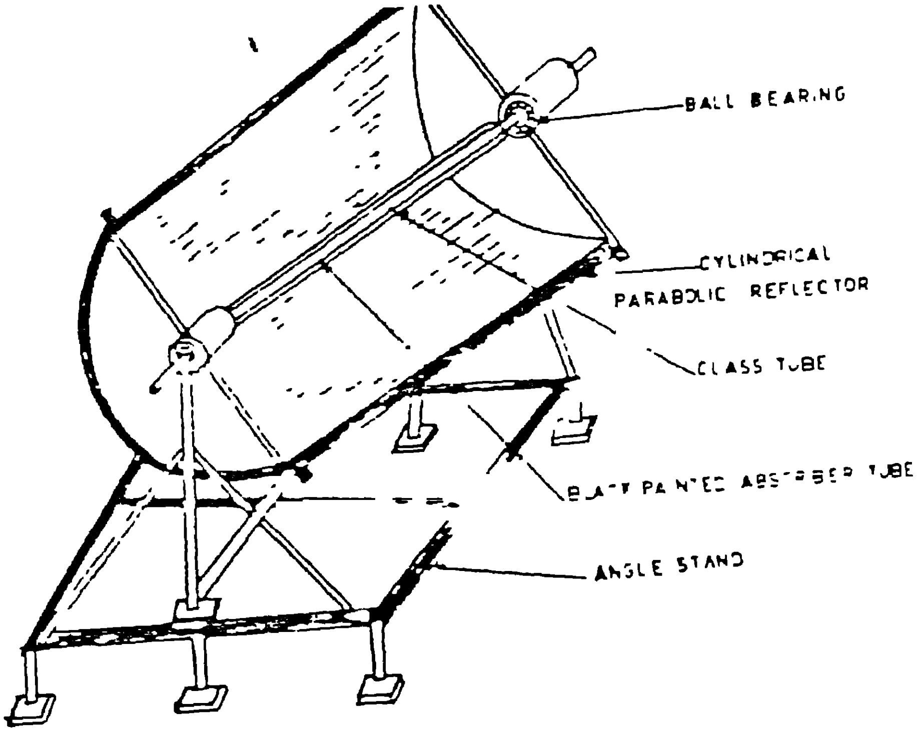


Fig. 13c

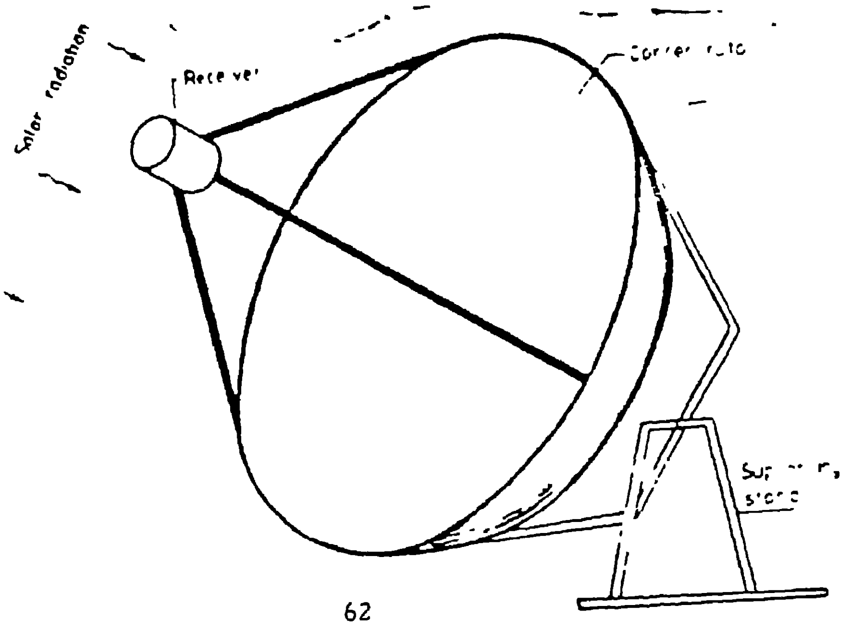


Fig. 13d

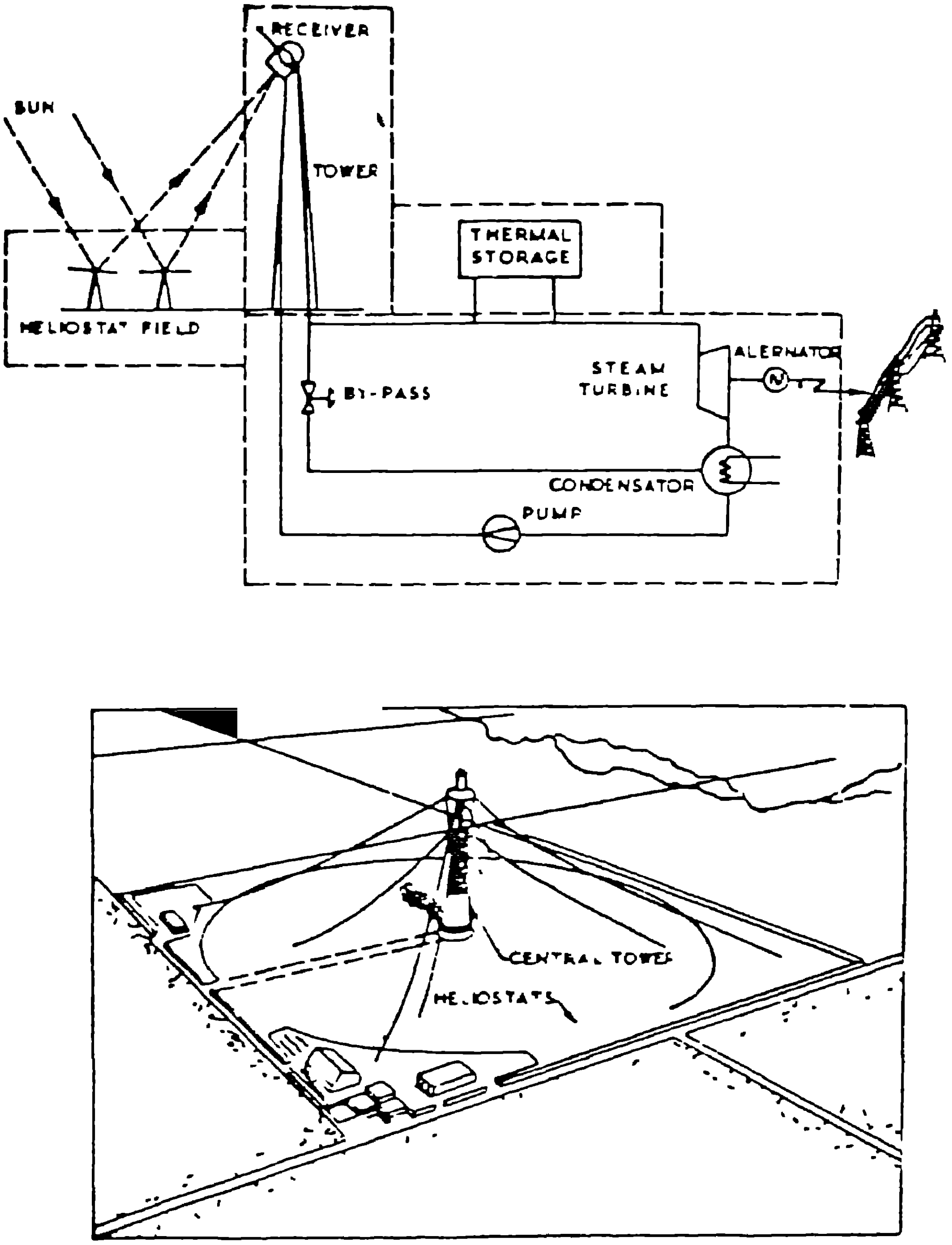

RECEIVER
SUN
TOWER
THERMAL STORAGE
HELIOSTAT FIELD
ALERNATOR
STEAM TURBINE
BY-PASS
CONDENSATOR
PUMP
CENTRAL TOWER
HELIOSTATS

Fig. 13e

rather than line focusing. The point focusing parabolic dish collector is shown schematically in Figure 13D. Such collectors have CRs ranging form 100 to a few thousand and can yield temperatures upto 2000^{o} C.

In order to concentrate large amounts of solar energy at one point, the central receiver concept (Figure13E) has been adopted, in which beam radiation is reflected from a number of independently controlled mirrors (called heliostats) onto a central receiver located at the top of a tower. Power stations with capacities upto 10 MW are being operated on an experimental basis in some countries.

Storage subsystems

The need for storage arises because in many situations there is a mis-match between the availability of solar energy and the needs of the application for which it is being used. There are three basic methods of storing thermal energy, viz. i) sensible heat storage ii) latent heat storage and iii) thermochemical storage.

The sensible heat storage is accomplished by heating a liquid or solid with high specific heat confined in insulated containers. The most common storage medium is water, which has the highest specific heat among liquids It can be used for temperatures below 100^{o} C. Also rockbeds are extensively used for storing heat especially for space heating applications. For temperature in the range of 100-300 °C heat transfer oils like Dowtherm, Servotherm etc. can be used. Some molten inorganic salts have been considered for thermal storage at high temperatures.

Latent heat storage is characterized by a change of phase, usually from solid to liquid. The heat can be stored at a single temperature level equal to the melting point of the material and hence different materials have to be considered for different temperature levels of application. Some of the phase changing materials tried for heat storage are $Cacl_2.6H_2O$ (30 °C), $Na_2So_4.10H_2O$ (32 °C) and paraffin waxes (45-60 °C).

In a thermochemical storage system, the solar energy to be stored is used to produce a certain endothermic chemical reaction and the products of the reaction are stored. When the energy is required to be released, the reverse exothermic reaction is caused to take place. Both reactions take place at constant but different temperatures. These systems are suitable for medium or high temperature applications only. Some of the reactions considered for thermochemical storage are given below :

$$CH_4 + H_2O \underset{610}{\overset{780}{\rightleftharpoons}} CO + 3H_2$$

$$So_3 \underset{590}{\overset{1025}{\rightleftharpoons}} So_2 + \tfrac{1}{2}O_2$$

$$NH_4 \cdot HSO_4 \underset{435}{\overset{498}{\rightleftharpoons}} NH_3 + H_2O + So_3$$

3.2.1 Applications of Solar Energy

Solar energy has been successfully used for various applications like water heating, steam generation, drying, space heating, refrigeration and air conditioning, cooking water pumping, desalination and power generation.

Domestic Hot Water (DHW)

Solar water heating for domestic purposes is perhaps the most widely used application of solar energy at present. A typical `natural circulation' or `thermosyphoning' water heating system is shown in Figure 14. The two main components of the system are the flat plate collector and the insulated storage tank, the tank being located above the level of the collector. As water in the collector is heated by solar energy, it rises automatically to the top of the water tank and its place is taken by colder water from the bottom of the tank. Hot water is withdrawn from the top of the tank and whenever this is done, cold water automatically enters at the bottom. An auxiliary heating system may be provided for use on cloudy or rainy days. This type of water heater is in widespread use in countries like Israel, Australia and Japan.

Forced Circulation Systems

Large amounts of hot water (at about 80 ^{o}C) are required in Dairies, textile industries etc. and also for hotels, hospitals etc. For such cases natural circulation

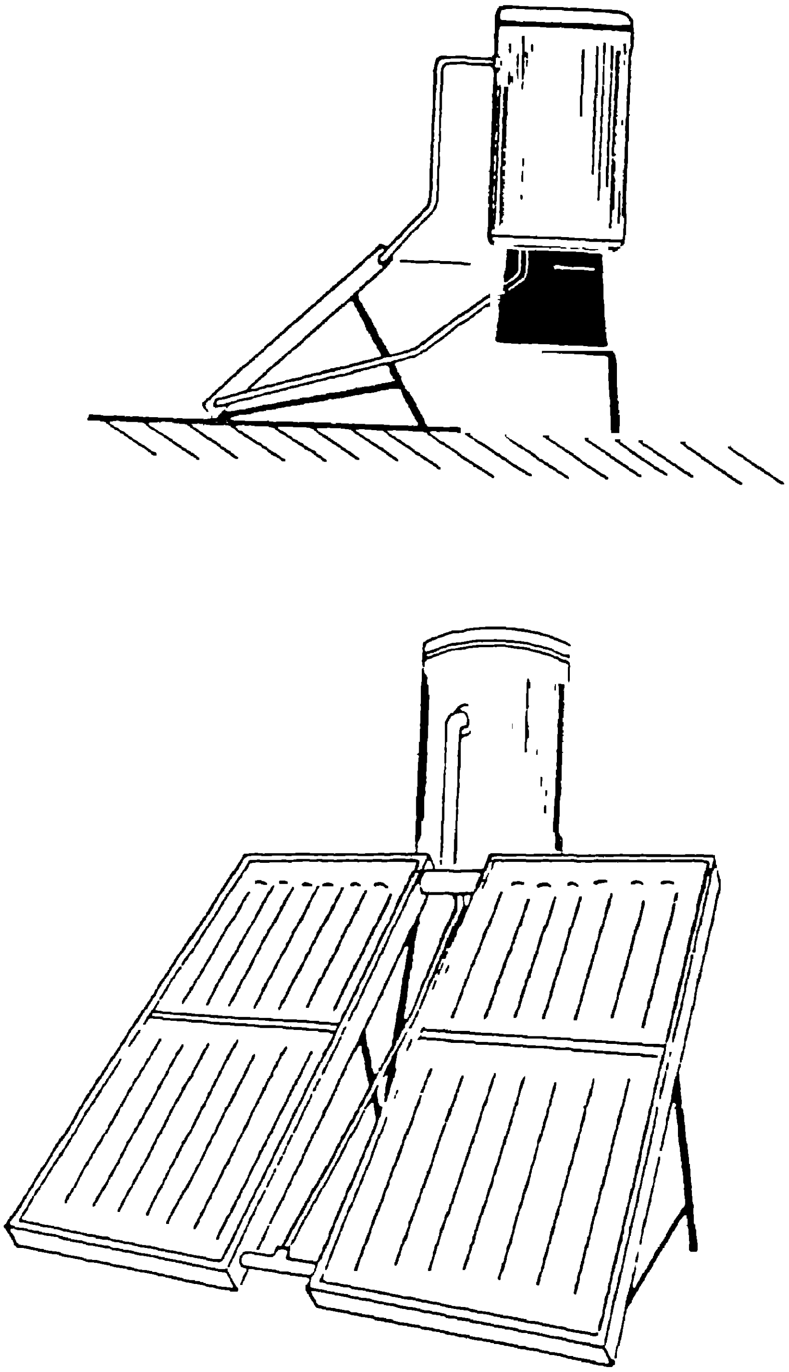


Fig. 14

systems are not suitable. Large arrays of flat plate collectors are needed and water is circulated by a pump. Also additional equipment for controls, demineralisation etc. is needed. A typical forced circulation water heating system is shown in Figure15. Such systems are installed in many places in India to provide hot water for dairies, textile mills, hotels etc.

Steam generation

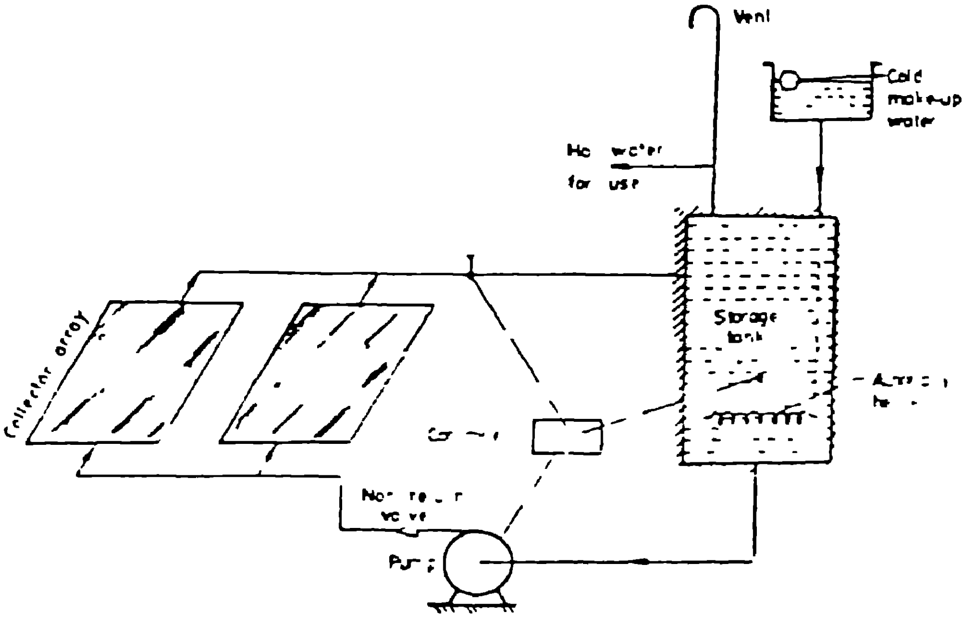
Generation of process steam for industries can be achieved by use of compound parabolic collectors, evacuated tubular collectors, linear parabolic concentrators or by a combination of linear parabolic and evacuated tubular collectors. Except for a few demonstration projects, the steam generating systems have not yet found place in Indian industry.

Drying

Hot air obtained from collectors very similar to the liquid flat plate collectors can be used to dry a variety of agricultural products like tea, tobacco, cardamom and grains. Both natural circulation driers and forced circulation driers have been used. Drying is done faster in this way than open sun-drying and in a controlled fashion.

Solar Space heating

Solar energy systems for space heating can be primarily classified as passive and active systems. In an active


Vent
Cold make-up water
Hot water for use
Storage tank
Auxiliary heater
Collector array
Controller
Non-return valve
Pump

'Fig. 15

system the collection and transportation of thermal energy is achieved by mechanical means i.e. pumps when working fluid is water and blowers when the fluid is air. Active solar systems (Fig. 16) are costly and require sophisticated controls which is not suitable for rural hilly regions. The passive systems on the other hand collect and transport energy by natural means i.e. radiation, convection and conduction. In a passive solar system the building itself is a part of the system as a storage unit.

The climate responsive architecture is age old. The Greek cities built around 500 B.C. were laid out with street patterns that provided each building site with access to the sun. Although, traditional architecture in hills is not solar based, the materials used in building construction are insulators and restrict the heat dissipation which is normally generated inside the building from fuel wood stoves. Moreover, the choice of the settlements indicates solar sensitivity as locations with more access to sun are used.

The simplest of the passive systems is the direct gain system which is illustrated in Fig. 17. The solar radiation that enters the interior of the building through glazed surfaces on walls or roofs is converted to heat when it strikes absorbing surfaces. At night heat is gradually released by convection and radiation from the surfaces.

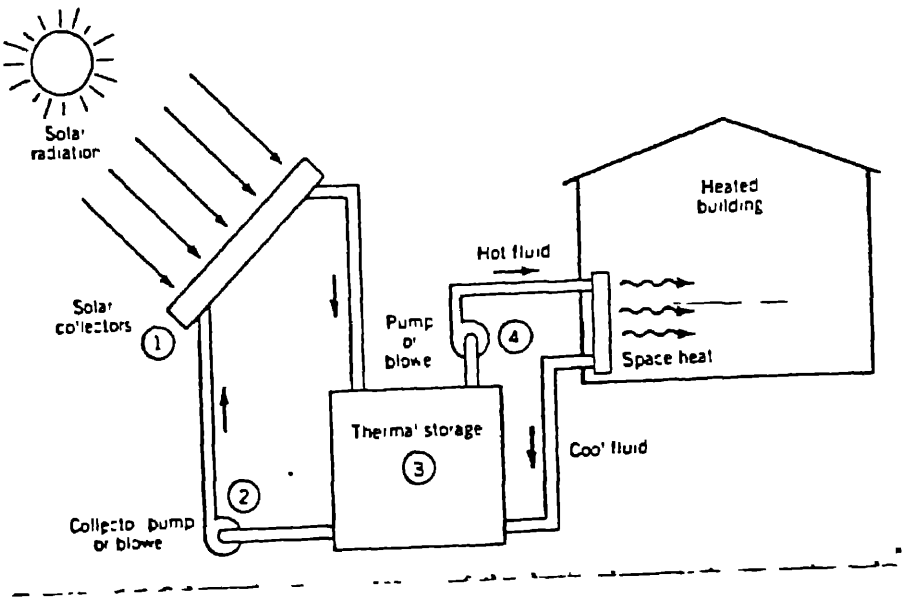

Solar radiation
Solar collectors
①
②
Collector pump or blower
Thermal storage
③
Pump or blower
④
Hot fluid
Cool fluid
Heated building
Space heat

Fig. 16

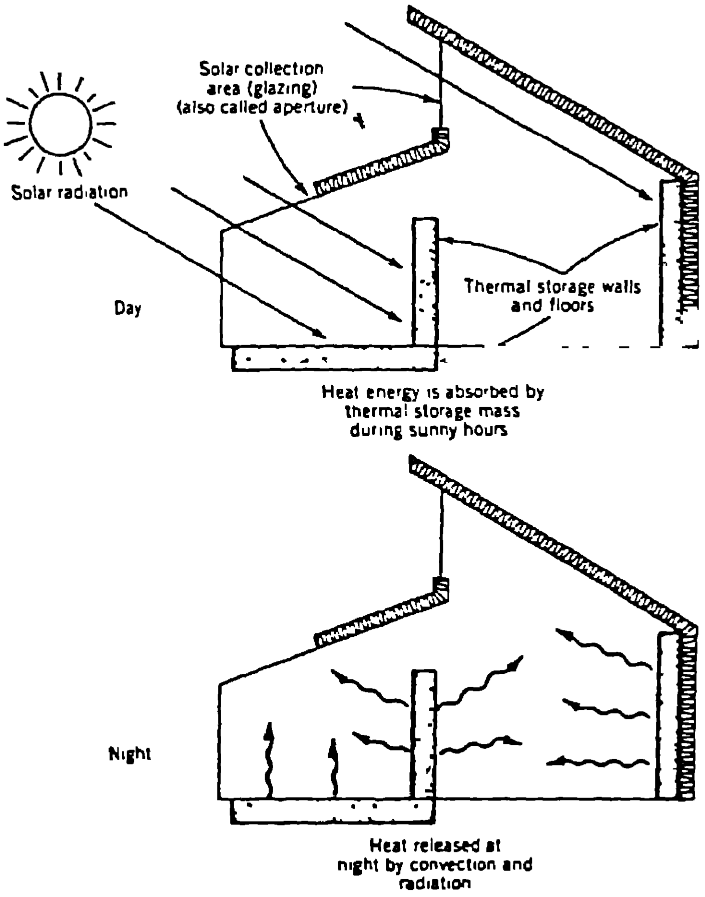

Solar collection area (glazing) (also called aperture)
Solar radiation
Day
Thermal storage walls and floors
Heat energy is absorbed by thermal storage mass during sunny hours
Night
Heat released at night by convection and radiation

Fig. 17

Alternatively a trombe wall can be used. It consists of a south-facing wall painted black on the outside, with a vertical sheet glass cover on the outside about 10 cm away. The gas between the black surface and the glass sheets acts as a radiation trap. Most of the heat passes which is released to the interior by conduction into the wall.

For a passive building to have good interior comfort the following conditions should be existing.

- To increase the response time of builing to changes in the ambient conditions, the structure must be coil insulated.
- Solar collection area should be adequate.
- In order to prevent uncomfortable temperature rise, careful distribution of thermal storage is required.
- There should be a provision for shading the solar collection area to prevent energy collection when not required.
- The rate of air infiltration should be low.

Cooking

Cooking is an important solar thermal application. Solar cookers are perhaps more known to the common public than any other solar device. A currently popular version is the box type solar cooker, shown in Figure19. It consists of a rectangular metal enclosure blackened and insulated at the bottom and sides and having two glass covers on the top. Food to be cooked is kept in

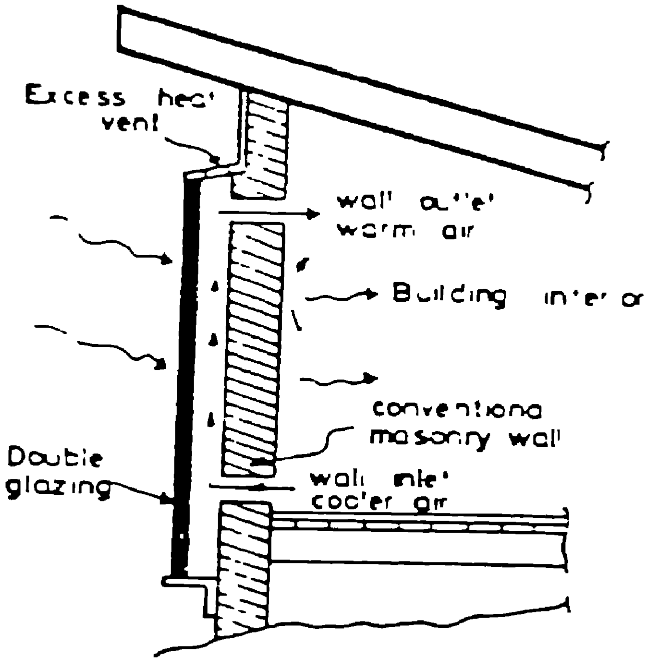

Excess heat vent
wall outlet warm air
Building interior
conventional masonry wall
Double glazing
wall inlet cooler air

Fig. 18

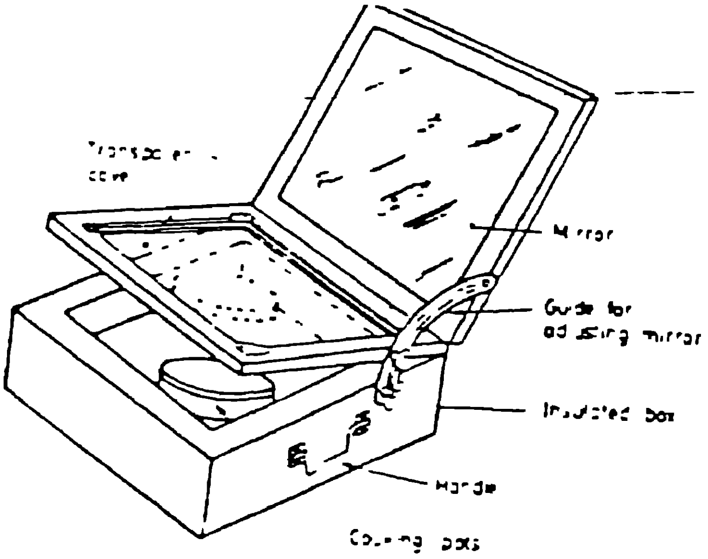

Transparent cover
Mirror
Guide for adjusting mirror
Insulated box
Handle
Cooking pots

Fig. 19

shallow, closed vessels blackened on the outer side and kept inside the box. The black surfaces absorb solar radiation and become hot and this heat is utilized in cooking. Rice, pulses, vegetables etc. can be readily cooked in this device. The cooking time is about 45 minutes to 2.5 hours depending on the food to be cooked and solar radiation available. A single glass reflector is sometimes attached to the cooker. These types of cookers can not be used as a complete substitute to conventional stoves because they cannot be used at night and they perform limited cooking operations. However, they can be used profitably as energy savers. It is estimated that, if the solar cooker is used regularly, a fuel saving amounting to Rs. 200 per year can be achieved. Concentrating type of cookers which use the parabolic dish collector are also available. These are more efficient and can perform all the cooking operations. The main problem is that they have to be manually tracked and hence require the constant presence of the cook. This type of cookers are being widely popularized in China at present.

Water pumping

Water pumping is one of the solar thermal applications which does not need storage. Owing to the relevance to developing countries, the solar water pumping systems have been extensively studied both in India and abroad. A schematic diagram of the prototype solar water pump developed at CSMCRI, Bhavnagar is shown in Figure 10. It relies for its operation on a low temperature organic Rankine Cycle, which is similar to the thermodynamic cycle operating steam engines. A refrigerant, usually Freon-11 is used as the working fluid. Freon-11 boils at low temperature in collectors, and the vapour generated is used to drive the reciprocating engine directly coupled to the recirocating water pump. The exhaust vapours are condensed by means of the pumped water itself, and the liquid freon is pumped back into collectors by a feed pump. Pistonless pumps with no moving parts were developed and studied at BITS Pilani, CSMCRI, Bhavnagar HBB Limited, Baroda and IIT Kanpur. A Solar pumping system similar to that shown in Figure 20 is developed by Dornier systems of West Germany and is presently under test at BHEL, Hyderabad. However commercial models of solar water pumping systems are not yet available in India Some studies indicate that solar water pumps are not economically viable at the present cost levels of collectors. Also, the technical problems associated with freon engines are not yet completely solved. Pumping systems based on concentrating collectors and steam cycle have also been developed, but they seem to be even more expensive than the flat-plate collector based systems.

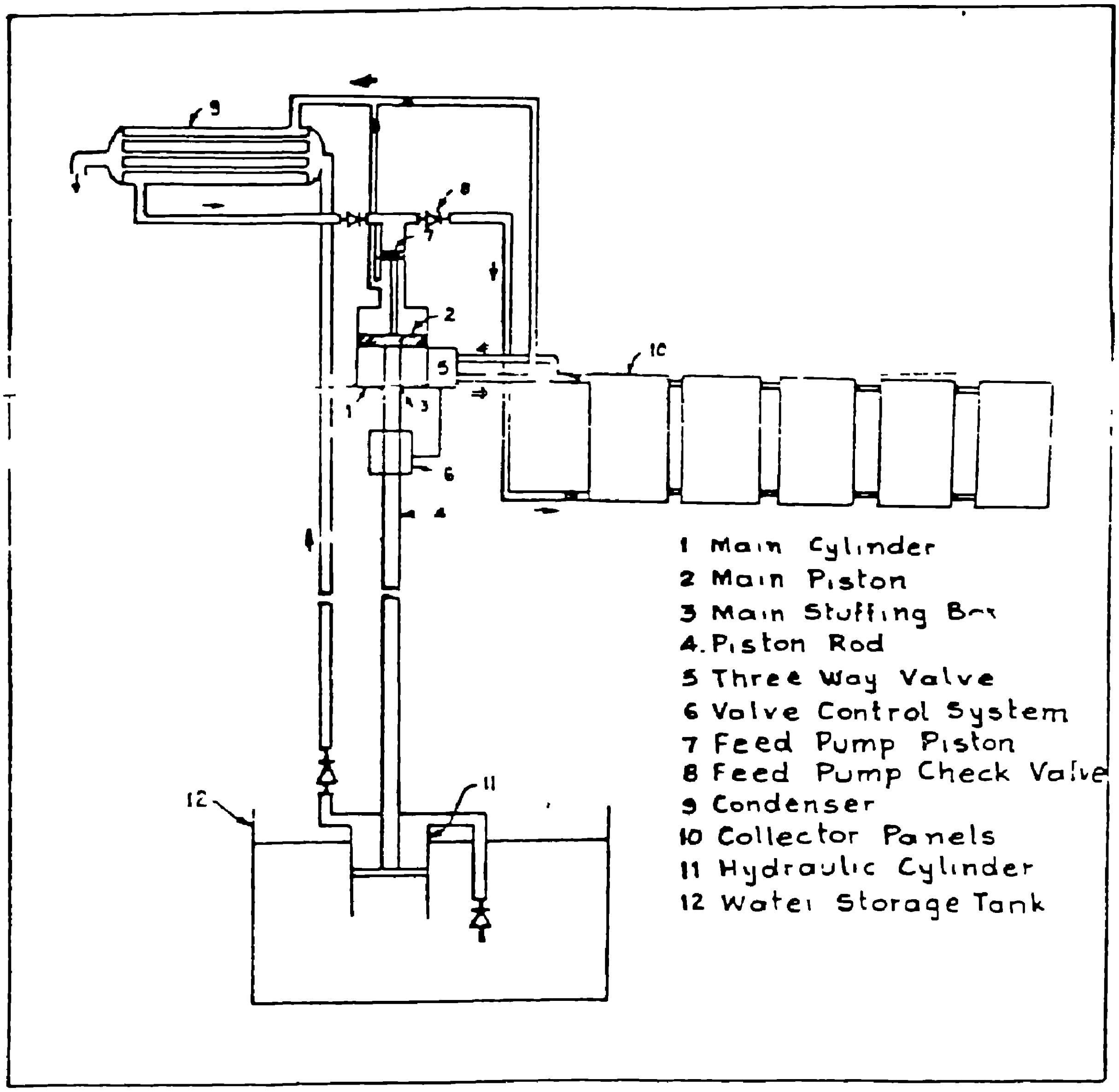

9
8
7
2
4
5
1
3
6
4
10
11
12
1 Main Cylinder
2 Main Piston
3 Main Stuffing Box
4. Piston Rod
5 Three Way Valve
6 Valve Control System
7 Feed Pump Piston
8 Feed Pump Check Valve
9 Condenser
10 Collector Panels
11 Hydraulic Cylinder
12 Water Storage Tank

Fig. 20

Desalination

Potable water can be obtained from saline or brackish water in a simple system called the solar still. A sketch of the solar still is shown in Figure 21. It consists of a basin with black liner with a sloping cover glass on the top. When exposed to the solar radiation the saline water contained in the basin gets heated and the vapours generated condense on the colder glass surface. The condensed water droplets trickle down on the condensate channels from where the fresh water can be withdrawn. The distilled water thus obtained can be used for drinking purposes and hospital uses. An output of 2-3 litres/m^2/day can be obtained in this way. A plant having a capacity of 5,000 litres/day is in operation in the village Awania near Bhavnagar.

Power generation

Almost all sorts of collectors have been tried for power generation through the solar thermal route. The low temperature systems, salt gradient solar pond in conjunction with an organic Rankine cycle turbine seems to be the most promising one with achievable electricity costs of Rs. 1.00-2.50/kWh. However, the economics of Solar Pond Power Stations (SSPs) seems to be attractive only in specific locations characterized by availability of waste land, low-cost salt or bittern, huge quantity of water etc.

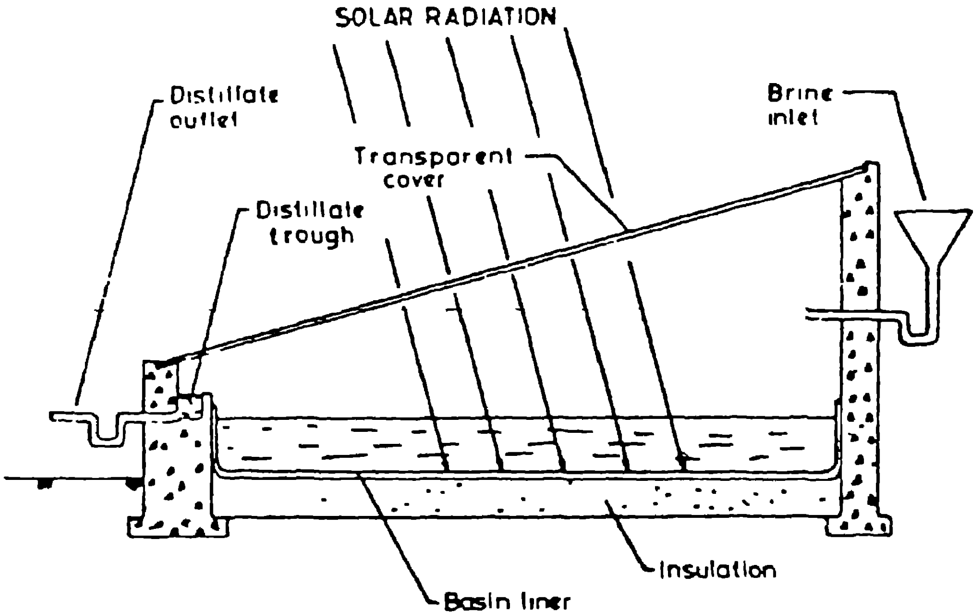

SOLAR RADIATION
Distillate outlet
Brine inlet
Transparent cover
Distillate trough
Insulation
Basin liner

Fig. 21

Linear parabolic and spherical parabolic collectors have also been used successfully for power generation. For high temperature collectors, the restriction of using freons as working fluids is absent and steam can be used just as in conventional thermal power plants. A concept which is gaining popularity at present is the central tower system 3 (they occupy lesser area than any other solar system). Experimental demonstration units of this type are in operation in Spain, Italy, USA and other countries.

As with many other solar systems, the huge initial cost is the major constraint coming in the way of wide acceptability of Solar Power Stations.

Solar Photo-voltaic Applications

Photovoltaic systems based on generation of electricity using solar radiation can be used as an alternative to conventional power supply systems. Silicon solar cells have been widely used for direct conversion of sunlight into electricity. A photovoltaic cell, module or array is rated for its peak power but the actual energy produced depends on the dried solar radiation. These have been tried for street lighting, water pumping, TV operation and can also be used to meet other energy needs. Another advantage of PV systems in hills is their performance does not depend on ambient temperatures. Table 14 shows the power requirements for a few applications in rural areas.

Table 14; Electrical energy needs and load pattern of different systems

System	Specifications	Working hours of the day	Power in kw	Energy in kwh/day
Agro-Irrigation	Area = 2 ha. γ = 3 mm/day d = 20 m η_d = 0.7, η_F = 0.5	08.00 - 16.00	1.16	9.3
Flour-mill	4 kw Motor	10.00 - 14.00	4	16
Potable water Supply	250w Pump-set	10.00 - 14.00	0.25	1
Community T.V Centre	(a) 25w FL+50w T.V	(a) 18.30 - 21.30	0.075	0.225
	(b) For adult literacy Centre Two 25w F.L	(b) 19.00 - 21.00	0.05	0.1
	(c) For Anchal Panchayat Office (one 25w. F.L	(c) 18.30 - 22.30	0.025	0.1
Domestic	One 25w. F.L.	19.00 - 22.00	0.025	0.075
Street lighting	One 25w. F.L	19.00 - 23.00	0.025	0.1

3.2 Technologies based on hydro resources

Micro Hydel

Even in traditional technology in the Himalayan regions microhydro power is used for the purpose of milling. A microhydro system can either have a low head and a large discharge or a high head and a small discharge. The microhydel sites in hilly regions normally have high head and small discharge. Microhydels in the traditional technology are used only as mills. The applicability and efficiency of such units can be increased considerably by only a few rectifications. The efficiency can be improved upon by the use of better bearings, better design and fabrication of the blades of primemover and better design and orientation of the chute of waterjet. The same primemover can also be adopted for a number of enduses like oil expelling, rice huller etc. Figure 11 gives the schematic diagram of such a system.

Although, a generator driven by microhydro can be connected to the grid, the option becomes increasingly attractive as a stand alone system for hilly rural settlement at a distance of more than 1 km from the grid and where the option of extending the grid is prohibitively costly.

The turbine for microhydel has to be designed keeping in view the fluctuating flow rates and part load conditions, therefore, a turbine characterized by a flatter efficiency curve is more suitable. Crossflow turbines have been found to be suitable for microhydro power generation.

The runner of a cross flow turbine is built of two parallel disks connected at the rim by a series of curved blades. The blades have simple cylindrical symmetry. These are horizontal axis turbines. The cross flow turbine is considered to be an impulse turbine, with all the pressure in the nozzle converted to velocity of the jet. One of the advantages of crossflow turbine is that because of the symmetry of its blades, the runner width theoretically can be increased to any value without changing hydraulic characteristics of the turbine. Efficiencies of commercial units lie in the range of 60-80%. Such turbines are available for

- Heads from 3 m to 100m
- Flow rates from 30 to 1500 lit/s
- Outputs from 5 to 150 kW.

The flow chart for microhydels is given in Figure 22 while the selection chart of crossflow turbines is given in Figure 23.

Other turbines that can be used for this purpose are pelton turbines and turgo turbines.

Hydrams

Hydrams use large flow of water under small head to deliver a smaller quantity of water to a higher

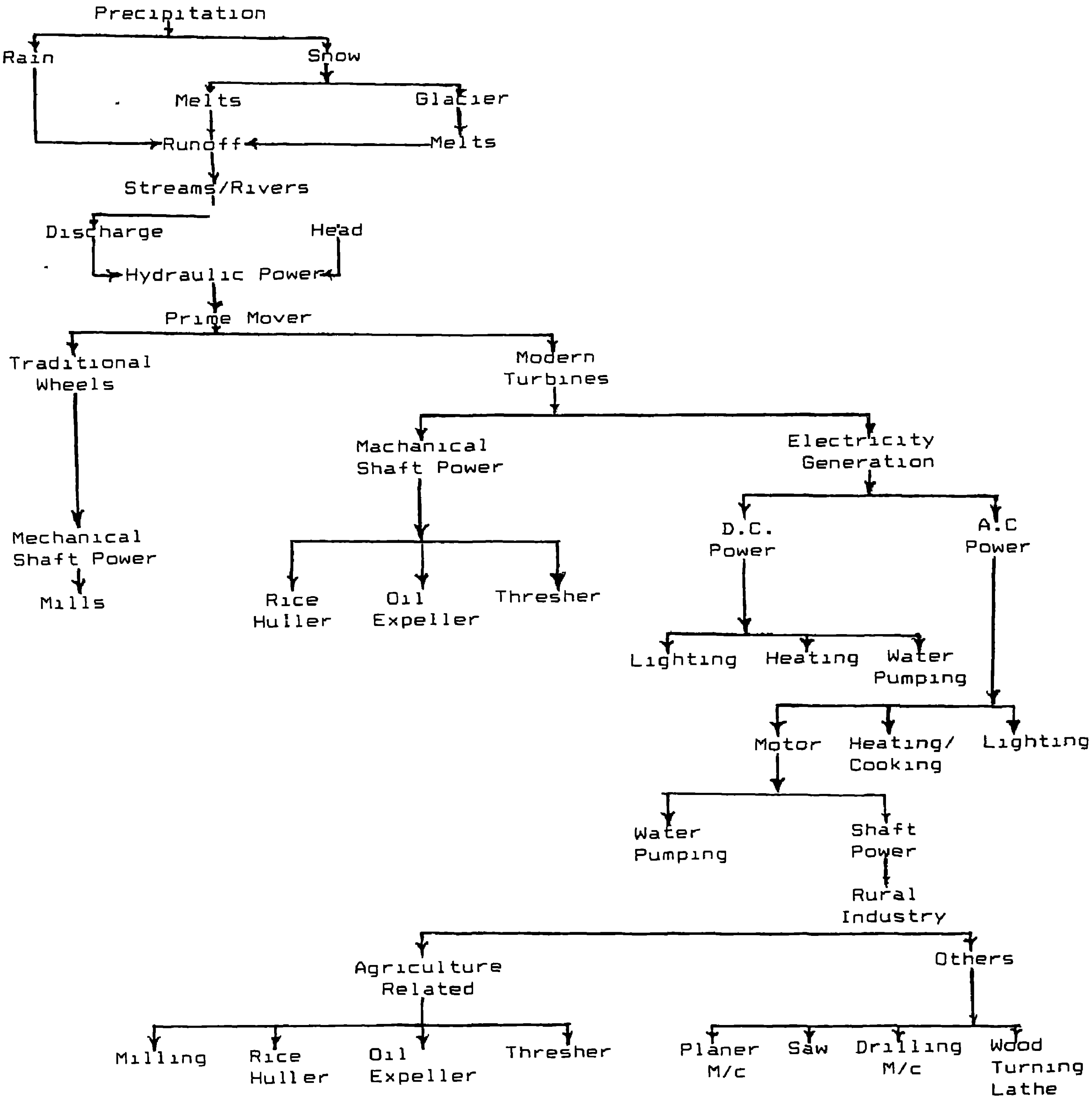
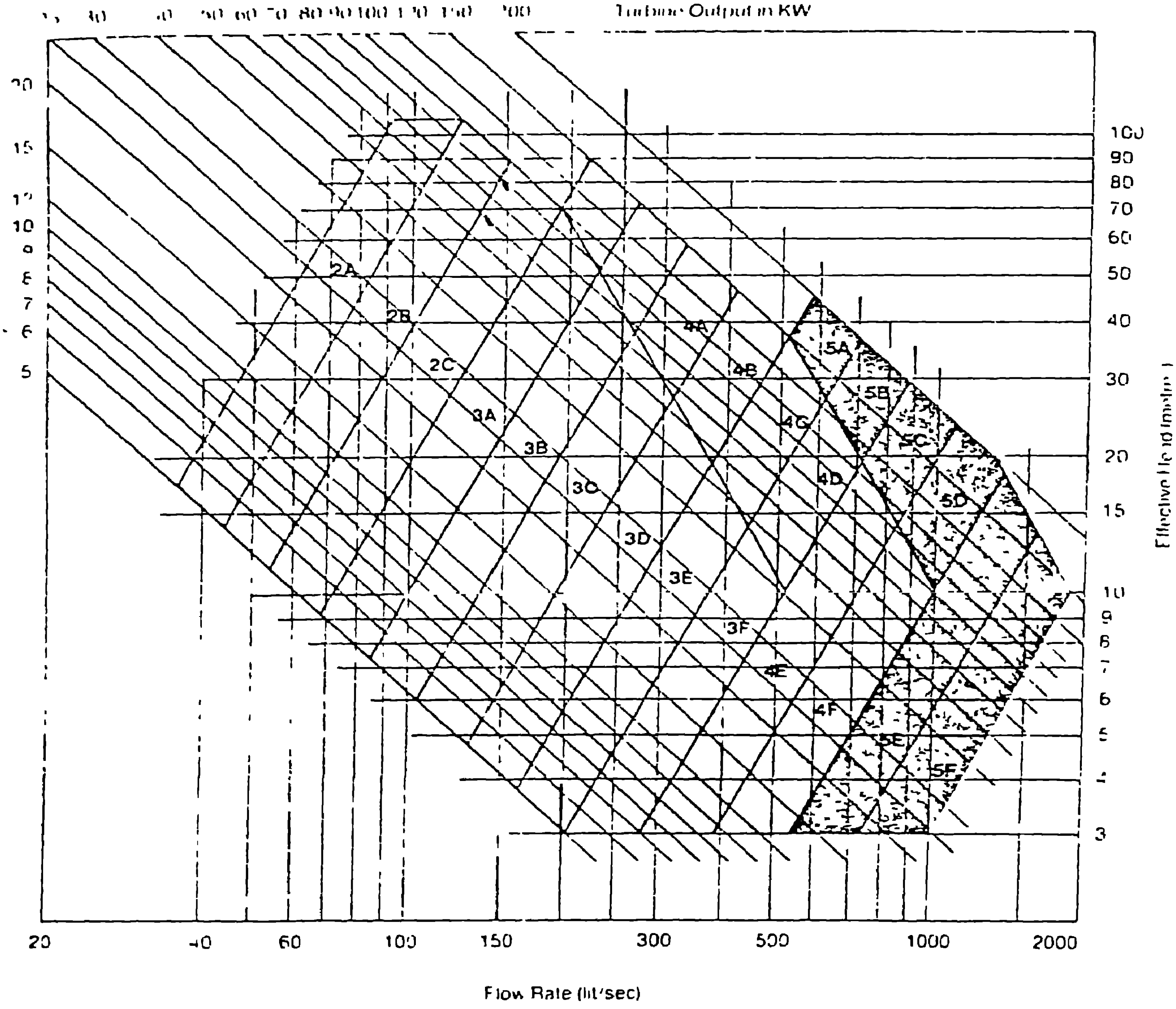


Fig 22: Flow Chart for Microhydels

Selection Chart

BYS T8 Series Crossflow Turbines



Example of Selection

Effective Head	35 metres	Turbine Model	4B
Flow Rate	400 litres/sec	Turbine Output	110KW

Fig. 23

elevation. A valve is arranged to close suddenly creating a shock, or water hammer, of high pressure which forces water to a higher elevation. The schematic diagram of a hydram is given in Figure 24. Hydram would be particularly useful for irrigating those sides of hills through which streams do not flow naturally. Hydrams are manufactured in many sizes, including 12" x 6", 8" x 4", 4" x 2", 2" x 1". Pump size is determined on the basis of the size of intake and delivery pipe. The model and size of hydram at a given site is determined on the basis of following criteria.

- Vertical fall from source to hydrams
- Vertical lift from pump to delivery spot
- Quantity of water available in the stream
- Quantity of water requirement at delivery spot
- Delivery pipe length from pump to delivery site
- Arrangement for unused water disposal
- Necessary space for laying the desired length of intake pipeline
- Minimum length of supply channel required to create the working head and also safety from flood, landslides etc.

H = fall or drive head
h = delivery head
L = length of drive pipeline
Q = water wasted
q = water raised/delivered
Q+q = total quantity of water required by Hydram

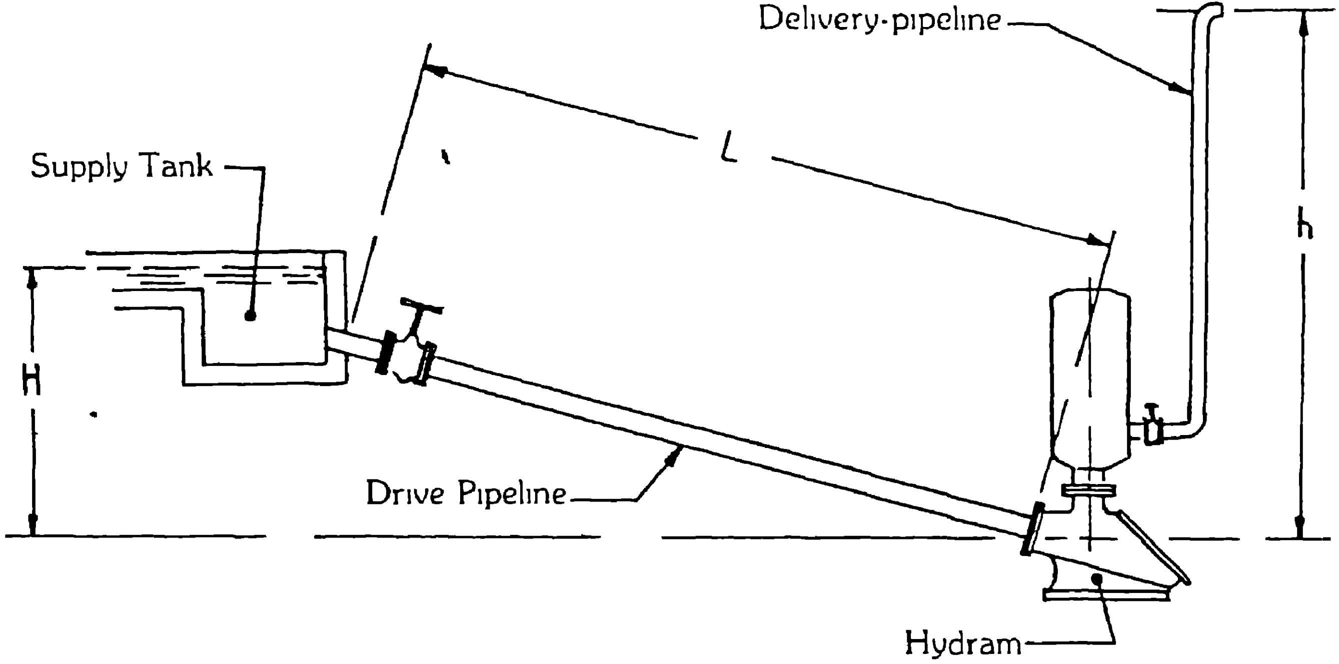


Fig. 24

3.3 Wind Technology

Windmills for water pumping

Though many organizations are involved in developing windmill designs, the only design that has been successfully disseminated in various parts of India is Apoly-12PU500 developed by the Institute of Engg. and Rural Technology, Allahabad. The technical specifications of this model are as follows:

1. Height of hub above the ground	7m
2. No. of blades	12
3. Diameter of rotor	5m
4. Theoretical rotor efficiency	38%
5. Cut in wind speed	2.5m/s
6. Cut out wind speed	10 m/s
7. Pump	
i)type	single acting, reciprocating
ii)piston diameter	155 mm.
iii)Stroke lengths	120 mm, 180 mm and 240 mm
iv)Output/stroke	4.5 litres at 240 mm stroke
v)Capacity	23,000 litres per hour at wind velocity of 10 m/s
vi)Volumetric efficiency corresponding to 240 mm stroke	82% at 3.5 m/s wind speed
8. Lifting Capacity	20 mts (Total Head)
9. Total weight of windmill	450 kg
10. Space required for windmill tower erection	2.25 m x 2.25 m

The discharge v/s wind speed plot is given in figures 25A to 25D corresponding to different lifting heads and different crank radii.

Table 15 gives the approximate area that can be irrigated by a single 12PU500 model windmill in

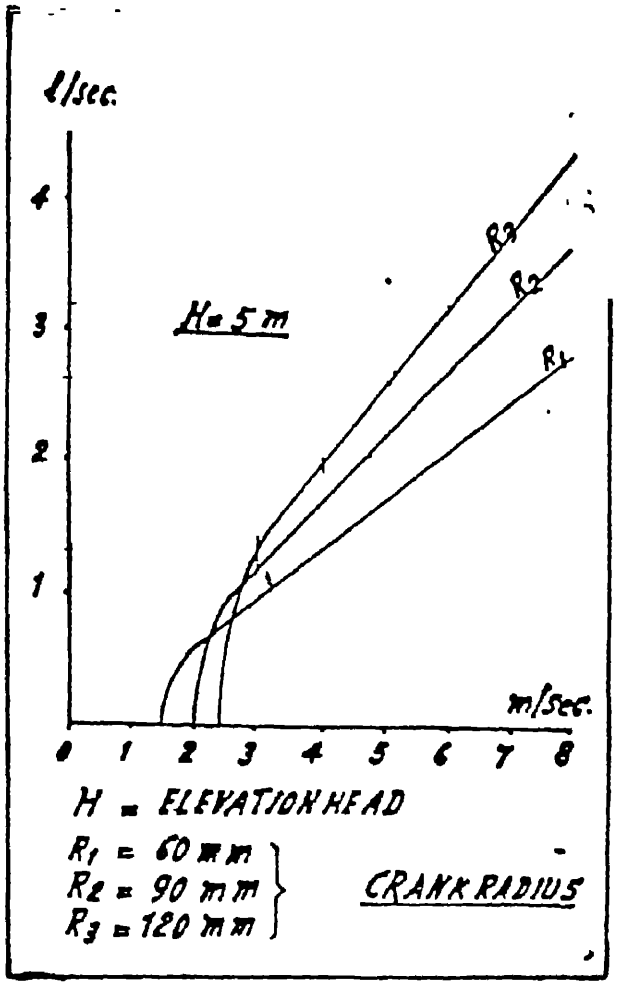


Fig. 25a

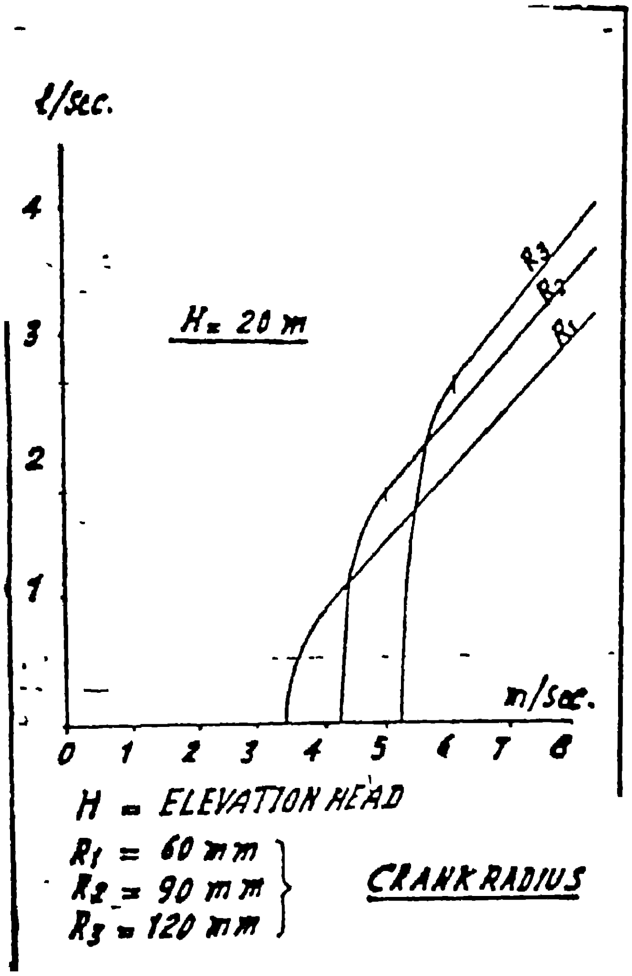


Fig. 25d

Discharge in liters per second corresponding to radii R_1, R_2 and R_3) versus prevailing wind velocity (V) in metres per second at 10 m elevation head.

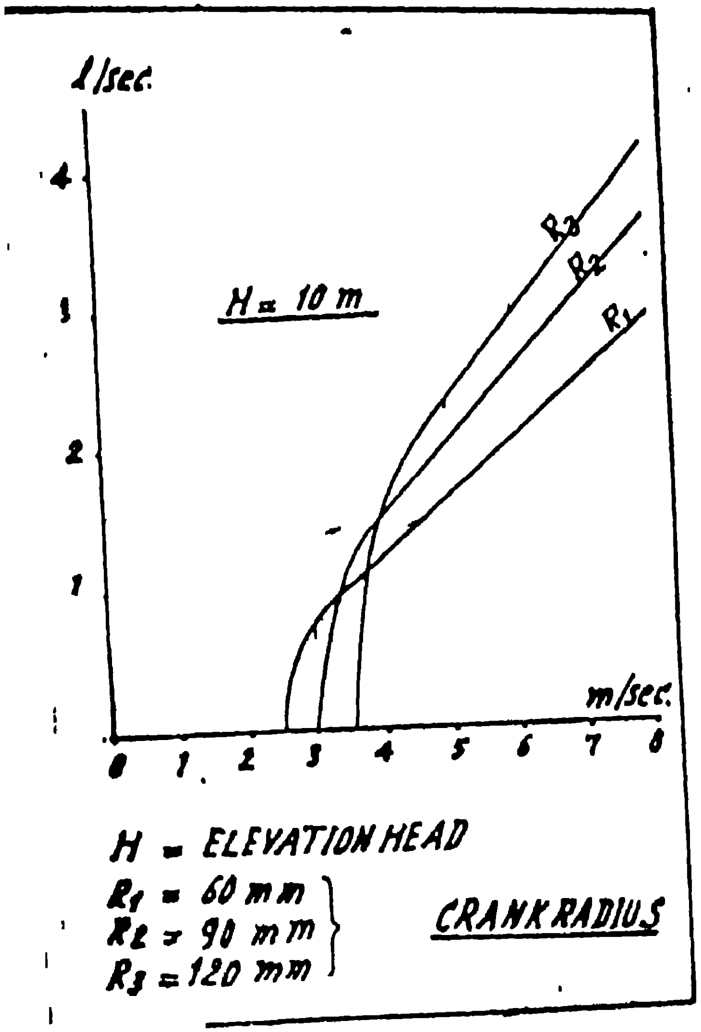


Fig. 25b

Discharge in litres per second (corresponding to radii R_1, R_2 and R_3) Vs. prevailing wind velocity (V) in metres per second at 15 m elevation head.

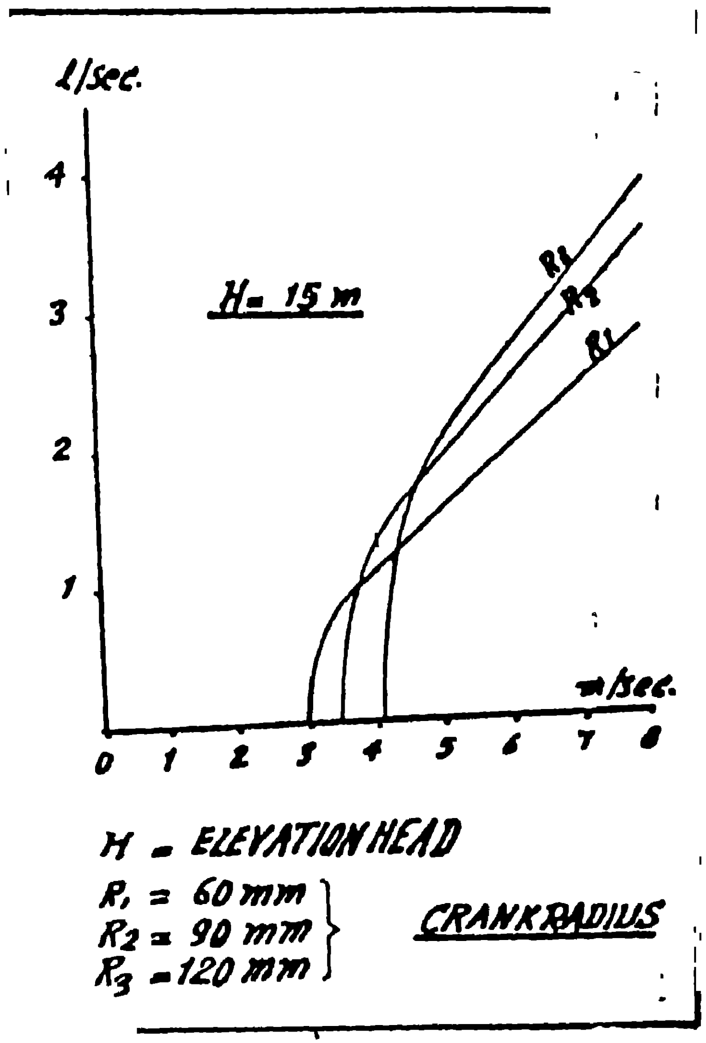


Fig. 25c

Table 15: Area irrigated by a Windmill Apoly - 12PU500

	Wind speed in m/s /Area irrigated (ha) lifting head = 5 m								Wind speed in m/s /Area irrigated (ha) lifting head = 10 m							
Crop[1] S.No.	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha
1	3	2.36	4	3.6	5	4.83	6	5.9	3	1.36	4	2.72	5	4.09	6	5.45
2	3	1.73	4	2.66	5	3.54	6	4.33	3	1	4	2	5	3	6	4
3	3	1.33	4	2.05	5	2.72	6	3.33	3	0.76	4	1.53	5	2.3	6	3.07
4	3	1.1	4	1.7	5	2.26	6	2.76	3	0.63	4	1.27	5	1.91	6	2.55
	lifting head = 15 m								lifting head = 20 m							
	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha	m/s	ha
1	3	-	4	2.27	5	4	6	4.9	3	-	4	1.45	5	3.09	6	4.72
2	3	-	4	1.66	5	2.93	6	3.6	3	-	4	1.06	5	2.26	6	3.46
3	3	-	4	1.28	5	2.25	6	2.76	3	-	4	0.82	5	1.74	6	2.66
4	3	-	4	1.06	5	1.87	6	2.29	3	-	4	0.68	5	1.44	6	2.21

1. Crop serial number is same as in Table 7.

Source : Apoly - 12PU500, Waterpumping windmill. A report by Wind Energy Research and Development Centre, Allahabad different average wind speeds and has been generated from figures 25A to 25D and Table 9. The values given in Table 15 are only indicative and may not represent the actual conditions. Any site can be evaluated for irrigation through windmills only by using the annual wind speed frequency distribution obtained from average hourly wind speed data. Such data is not collected even for meteorological purposes and exists only for a few anemometer stations throughout India.

Wind electric Converters

Wind electric converters (WEC) can be used in two modes. As grid connected generators to produce grid quality electricity or as stand alone systems. The grid connected (WEC) normally uses induction generator which is cheaper and more suitable for rugged applications. The stand alone systems can either be just battery chargers or can be coupled to the diesel generating sets. The stand alone systems run a synchronous generator or a permanent magenet alternator.

Grid connected WEC approaches viability in areas with very good wind regimes (annual avg wind speed 5 m/s or above) which are found only in coastal areas, therefore, these systems have limited applications for hills. On the other hand stand alone system coupled to a diesel generator to provide uninterrupted power supply to a remote isolated settlement seems to be a more attractive option even though the site may be moderately windy.

Battery chargers with a capacity of a few kilowatts are suitable for areas where instances of lower wind speeds are higher as the rotor of such systems have a low cut - in wind speed. In hilly regions windspeeds may vary considerably even within the neighbourhood of a location depending upon altitude, slope and obstructions. In general, ridges are considered good as sites. A ridge acts as a sort of concentrator for the air stream, causing the air to accelerate near the top. The effect is stronger when the ridge is rather smooth and not too steep nor too flat. The ideal slope angle is said to be 16^{o} (29 m rise per 100 m horizontal distance) but angles between 6^{o} and 16^{o} are considered good. In case of hills the wind tends to flow around the hill so that the hill sides, perpendicular to the prevailing wind may experience higher wind speeds than the hill top. In certain locations passes, saddles etc. may also experience good wind speeds. Siting for windy sites in complex terrain is a subject in itself and a more detailed explanation would be out of the scope of this study.

The technical specifications of a 75 kW grid connected WEC which is installed in some of the coastal areas in India are given in Table 16 while those of stand alone systems are presented in Table 17. Figures 26 and 27 give the power characteristics of these systems. The stand alone wind diesel systems are yet to be installed

Table 16 : Technical Specifications of a 75 kW grid connected WEC

Rotor Diameter - 17.0 m

Swept Area - 227 m

Blade type - vestas 8.5 m

Rotor Speed (synchronic) - 45.0/35.5 r.p.m.

Generator speed - 1000 r.p.m.

Gear Ratio - 1:22.2

Generator - 90/19 kW induction type

Wind vane - opto electronic

Anemometer - opto electronic

Hub height - 23.5 m

Cut in wind speed - 3.5 m/s

Rated wind speed - 13 m/s

Cut out wind speed - 25 m/s

Voltage limits - 415 ± 10%

Phase assymetry - 10%

Frequency - 50 HZ ± 1 HZ

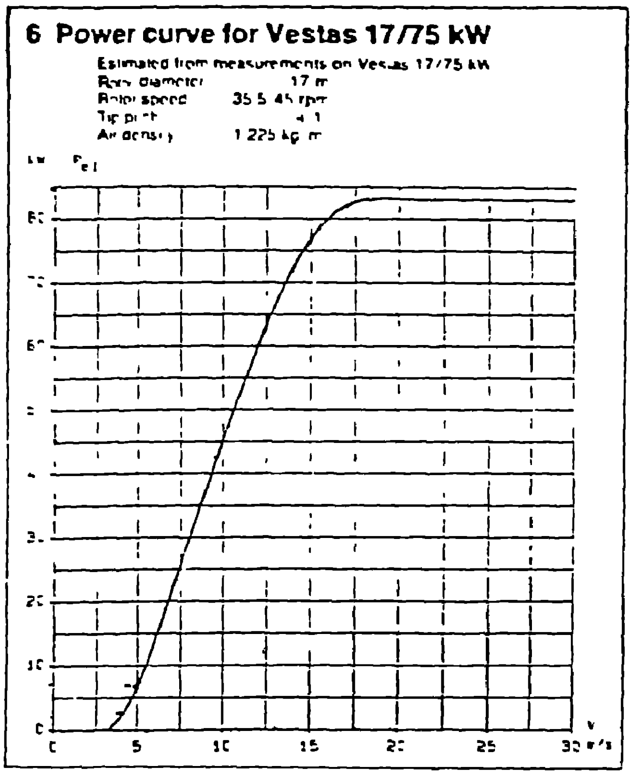
Source : Technical Literature provided by manufacturers

Vestas Energy Systems A/s

Table 17 : Technical Specifications of Stand Alone System

	1 kw WEC	10 kw WEC
Start up wind speed	2.2 m/s	3.4 m/s
Cut in wind speed	2.2 m/s	3.1 m/s
Rated wind speed	9.0 m/s	12.1 m/s
Cut out wind speed	none	none
Furling wind speed	-	15.7 m/s
Blade type	NACA 44/2	-
No. of blades	3	3
Rotor type	3 Blade upwind	3 blade upwind
Rotor diameter	3.0 m	7.0 m
Weight	`00-' g	463 kg
Blades pitch control	-	Power flex
Cover speed protection	Electrical brake and by turning the tail by 90o	Furling
Generator	1 kW permanent magnet	10 kW permanent magnet
Make of WEC	LMW Wind Energy	BWC Excel

Source : Technical literature provided by manufacturers



6 Power curve for Vestas 17/75 kW

Estimated from measurements on Vestas 17/75 kW

Rotor diameter 17 m

Rotor speed 35.5/45 rpm

Tip pitch +1

Air density 1.225 kg/m³

Fig. 26

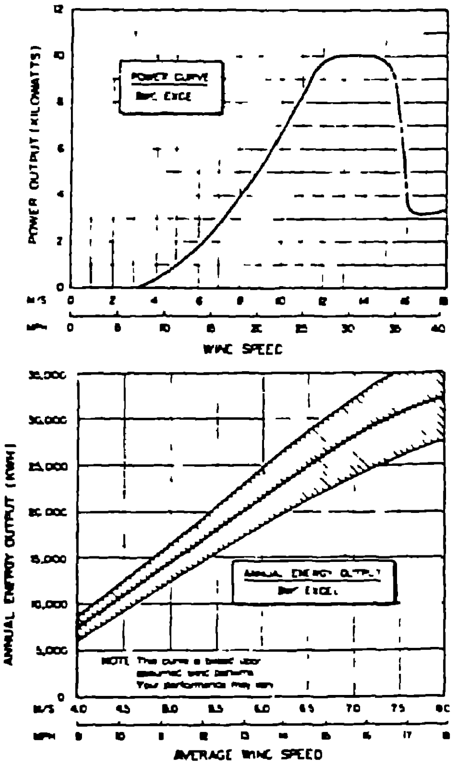

POWER CURVE
BWC EXCEL
POWER OUTPUT (KILOWATTS)
0
2
4
6
8
10
12
M/S
0
2
4
6
8
10
12
14
16
18
MPH
0
5
10
15
20
25
30
35
40
WIND SPEED
ANNUAL ENERGY OUTPUT
BWC EXCEL
ANNUAL ENERGY OUTPUT (KWH)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
NOTE: This curve is based upon
assumed wind patterns.
Your performance may vary.
M/S
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
MPH
9
10
11
12
13
14
15
16
17
18
AVERAGE WIND SPEED

Fig. 27

in India. Therefore, it is not possible to discuss the economics of such systems. Stand alone systems can also be used for pumping water for irrigation. The performance of a 10 kW WEC for this purpose is given in Table 18. Flowchart for a wind electric system is given in Figure 28.

Table 18.1: Water Pumping Characteristics of a Typical 10 kW WEC

Average Annual Wind Speed m/s	Daily Water Delivery m3
3.5	43
4	76
4.5	117
5	162
5.5	211
6	260
6.5	306
7	349
7.7	385
8	416

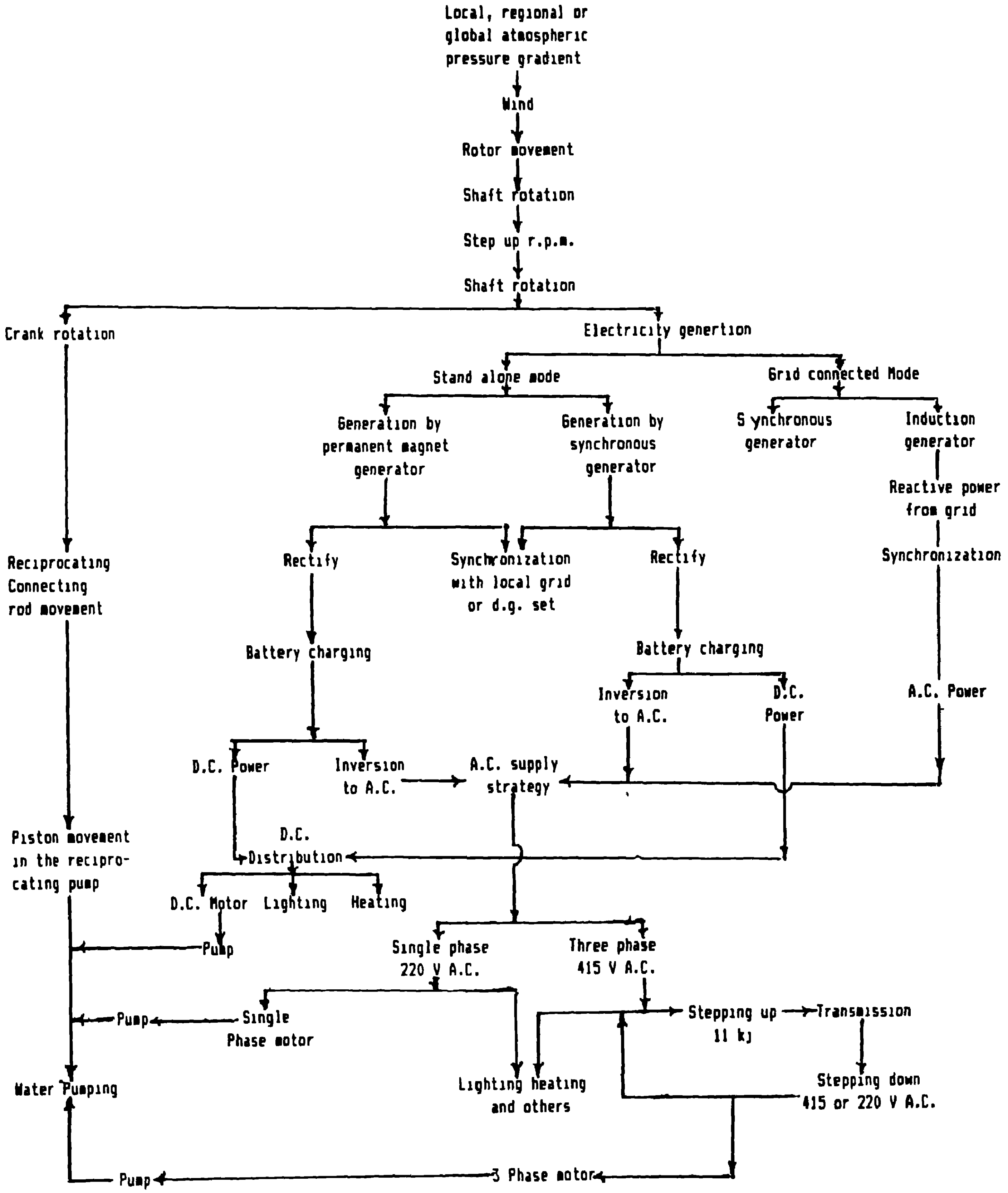


Fig 28 · Flow Sheet for Wind Mills

3.5 Conservation Measures

Apart from the adoption of various modern technologies in place of the traditional ones, a considerable scope exists for improvement in traditional technologies, methods and devices. Although, in principle these technologies can be replaced by any of the appropriate technology options discussed earlier, it would be erroneous and farfetching to assume that this can be achieved in near future by the district planner due to the financial, social and infrastructural constraints that always come into play while changing over from one option to another. Therefore, the lesser technologies (not the least) like those based on animal power or the household devices like kerosene lamps will continue to contribute a significant amount of energy conversion. An improvement in efficiency of such systems may not always effect the overall energy consumption of the district but it will definitely improve the living conditions of the hill folks.

Animal power in a way can be treated as a nonpolluting renewable energy source and hence as long as it serves the purpose its replacements is not desirable. In hills animal power is mostly used as a source of draught power for field operations in agriculture. Presently majority of the farmers in hills use the traditional inefficient wooden ploughs normally worked with bullocks. Animals are also used in the traditional oil expellers `kohlu' or for operating waterwheel. It is not possible to get an exact break up of animal energy used for different enduses but ploughing operations do utilize a considerable amount of animal energy. An improvement in ploughs would result in a significant increase in the efficiency of utilization of animal energy source. Some of the factors that should be considered while designing a better plough are

- The shocks should be minimized i.e. the surface of the ploughs should be smooth.
- Plough should be designed in such a manner so that it enters the ground at the best angle.
- The size of the plough should be again decided on the basis of the ease of operation and the depth to which land is prepared.

The efficiency of oil expellers and waterwheels can also be improved upon by using better bearings, lubrication oil and selection of right dimensions for the centre shaft and the driving lever.

Animal powered lifts for irrigation are hardly found in the hills, however, a comparison of different methods of water lifting by animal power is given in Table 19.

Table 19 : Types of animal operated lifts

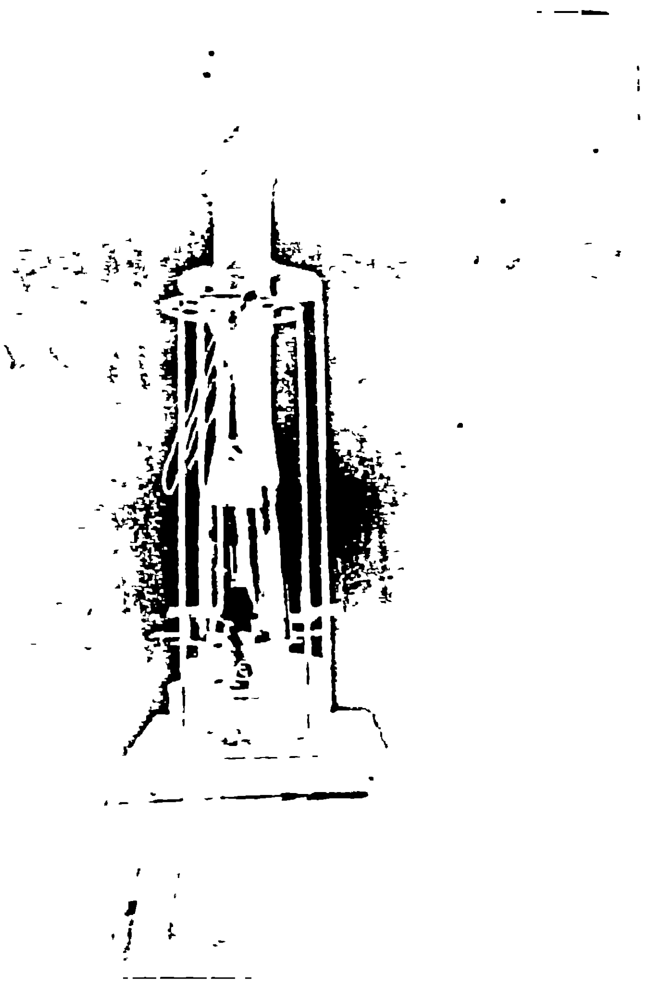
Type of lift	Required Power Source	Optimum Lift (metres)	Average Discharge (lit/hr)
Rope and Bucket	2 pairs of animals	10 to 30	6,000-10,000
Chain Pump (washer rubber)	1 pair of animals	3 to 6	15,000-20,000
Water wheel	1 pair of animals	1 to 2	40,000-60,000
Persian wheel	1 pair of animals	5 to 10	15,000-18,000

Source : APDC, Integrated Energy Planning, 1985

The commonly used kerosene lamps for lighting are chirag, hurricane and organ. The light quality for all the three is poor. Better lighting can be achieved by lamps like petromax but these are costly which the common folks can not afford. Some work has been done on improving the commonly used kerosene lamps. One of the improved models `Noorie' developed by Nimbkar Agricultural Research Institute is shown in Figure 29 and is compared with commonly used ones in Table ~~8~~ 10. The efficiency of such lamps can be further improved by using more efficient thermoluminescent salts for mantles.

Table 20 : A Comparison of different types of Kerosene Lamps

Lamp Type	Kerosene Consumption (g/hr)	Light quality	Cost
Chirag	6	Poor	10
Hurricane	14	Poor (Light output equivalent to 4-6 candles)	36
Organ	21	Poor (Light output equivalent to 4-6 candles)	
Noorie	28	25 W electric light, 245 lumens and 3.56 times better than hurricane	75
Petromax	80-85	60-100 W electric light	250-300



Noorie (Kerosene) Lantern

Fig. 29

4. EVALUATION FRAMEWORK

Based on the enduse characteristics in the region and on the development plan it is possible to identify the energy needs of a district. The assessment of energy resources and a knowledge of energy technologies equips the planner with the base line information necessary for preparing an energy development strategy. As a broad framework in the evaluation of energy technology options following steps can be used :

i) Identification of energy needs
ii) Examination of traditional energy supply systems
iii) Listing of possible solutions to alleviate the energy needs
iv) Short listing of the energy technology options
v) Environmental Impact Assessment
vi) Techno-economic Evaluation
vii) Consideration of socio-cultural and other factors
viii) Evaluation of the impact on energy consumption pattern in the area

We can now discuss some of the points to be considered in each one of these steps.

1) Identification of energy needs : The methods to identify energy needs have been discussed in a separate chapter and would be formulated based on the existing energy consumption pattern, future demand, needs of further development eg. Conservation of energy use in domestic activities to reduce absolute energy

consumption, energy needs of expansion of tourism complexes in the district, energy needs of water pumping in the district etc.

ii) Examination of traditional energy supply systems : An energy supply system includes fuels, their price and availability. It also includes energy conversion devices and other enduse components. In case of lighting kerosene supply, lamp, location of use, time and duration of use are important. A knowledge of this is essential for an enduse oriented approach to alleviate energy problems. [A supply oriented approach can concentrate on increasing the supply of fuels and the enduser makes decisions regarding the choice of fuel mainly based on financial viability. But in a situation of fuel scarcity besides price, availability becomes an overriding criteria in the selection of an option eg. use of diesel pumpsets along with electric pumpsets.]

iii) Listing of possible solutions to alleviate the energy needs : A variety of solutions are possible to move towards a desirable energy consumption pattern. A desirable energy consumption pattern is country specific and within a country it will be area specific. But it broadly sets directions for choice of solutions eg. in a denuded hilly district of a resource limited fuel scarce country a desirable energy consumption pattern would be to move away from the use of biomass, to limit the use of commercial fuels and to use renewable energy resources extensively.

iv) Short listing of the energy technology options : It is possible to shortlist the technology options based on the priorities using the energy technology specifications in section 3 of this chapter.

v) Environmental Impact Assessment : EIA is very critical in the hills and should have a decisive role to play eg. large scale use of gasifiers based on energy plantation is probably not desirable in the hilly areas with inadequate forest cover. Hence besides the environmental impact of use of a technology it will be essential to see whether in the long run it adds to environmental/ecological stability.

vi) Techno-economic Evaluation : Methods of economic analysis have been described elsewhere in the manual. Appendix I also explains the method of Levelised Annual Cost and is used to evaluate power generation options. While comparing alternatives, it is important to choose whether to compare i) costs of thermal/electric energy generation, ii) costs of equivalent systems for an enduse.

For industrial energy needs or for supply augmentation it will be adequate to compare alternative fuels to provide thermal and electrical energy but for specific enduses it is important to evaluate the equivalent energy supply systems. This is particularly required in household or agricultural sectors where decisions are based on fulfillment of energy needs of specific enduses. Appendix II gives some of the technology parameters for cooking, water pumping and lighting and can be used in arriving at equivalent systems. Analysis of financial viability is essential in such cases.

vii) Consideration of socio-cultural and other factors : The viable options may not be effective due to socio-cultural factors and hence these need~~s~~ to be considered. Proportion of solar cookers is a typical example where socio-cultural factors and dwelling types have played a significant role in limiting their use.

viii) Evaluation of the impact on energy consumption pattern in the area : The possible impact of an intervention needs to be gauged before the intervention is made and then a monitoring would bring out the deviation in reality from the estimated impact. Besides meeting the energy demand the objective is also to move towards a desirable energy consumption pattern.

Appendix I

Decentralized Power Generation Options

The computation of the cost of generation is based on the Levelized Annual Cost (LAC.) approach. The LAC. is given by the formulation

$$\text{LAC.} = \frac{\text{Annualized Cost (Rs.)}}{\text{Annual net electricity generation (kWh)}} \qquad -(1)$$

The annualized cost is defined as :

CRF X I + Annual O&M costs + Annual fuel costs -(2)

where I is the capital cost (Rs.) and C.R.F., the capital recovery factor is given by

$$CRF = r/[1 - (1 + r)^{-OL}] \qquad -(3)$$

and r = discount rate

OL = system operating life

For all the systems discount rate can be assumed to be 12% per annum. The LAC approach is equivalent to the Net Present Value (NPV) method of evaluation.

This approach can be used to evaluate decentralized power generation options. The conventional method of providing electrical energy in the hill regions is through the extension of the regional power grid. However, a large number of isolated small settlements remain unelectrified due to the prohibitive costs of laying the transmission lines. Electricity generation and transmission in hills can be achieved in a decentralized manner from any of the suitable options listed in Table 1. The renewable energy options like wind, solar and hydro are subject to fluctuations at the source and hence in the power output. The optimum utilization of such options can be achieved by matching the daily load pattern with the power availability. Therefore, a change in the use pattern and habits may be required. In case uninterrupted power supply is required then one has to essentially consider hybrid options. Depending upon the potential for various options a number of hybrid power generating combinations can be planned. The two components of such a system would be from an assured power source and a fluctuating power source. A small energy storage capacity may be required to reduce the number of stops and starts of the assured power source, the storage can be either in the form of batteries or flywheels.

Although, the hybrid systems have a large potential for hilly regions, they have not been tried so far even on an experimental basis. Therefore information regarding costs and performance is not available. The generation from the technology options based on fluctuating renewable energy sources differs from site to site and is a function of the temporal frequency distribution of the rate of flow of the working fluid i.e. wind speed distribution for wind mills or discharge distribution for microhydels. The assured power source can either be based on commercial fuels (diesel generating sets) or biomass based fuels (gasifiers + dual fuel engine). The objective of an autonomous hybrid system would be to save as much fuel as possible whilst keeping investment costs as low as possible. The variables that can be manipulated with a view to optimize the system would be

1. Loads
2. Diesel genset or dual fuel engine capacity
3. Storage

The system design for hybrid system would involve

- Determination of the optimum mix of assured and fluctuating power sources in the generation capacity.
- Determination of the optimum storage size
- Load management

One of the possibilities in hybrid systems or stand alone systems would be the power availability even in excess of storage, for such instances energy has to be dumped. This excess energy can be used to meet the requirements of space heating, water heating or cooking.

It is possible that a considerable potential for renewable energy options exists at locations which are already connected to the power grid or are in its near vicinity (say within 1 km). In such areas wind electric converters or solar based power generators or microhydels can be connected to the grid. A generation source near the loads would result in low transmission losses. The grid connected generators are normally induction generators which are cheaper and more rugged as compared to the synchronous generators. The overall generating capacity of these should be less than the minimum load on the local grid as the induction generators take the exitation current from the grid. The decision for a given system option would depend on the overall economics of power generation from the system. The values of LAC for different technology options for power generation is listed in Table 21 while the LAC for different models and different head ratios of hydrams is given in Table 22.

Table 81: LAC of Power Generation from Various Technologies (Rs./kWh)

Thermal Power Station	0.623 - 1.286
Diesel Generators	1.33
Small Hydro Power	1.26
Dendrothermal power plants	1.44
Windfarms	1.49
Wood gasifier power plants	1.50
Briquetted agrowastes (gasification)	1.78
Briquetted agrowastes (direct burning)	1.82
Dish Stirling Solar Electric	5.0
Solar Pond	6.80
OTEC	11.5
Photovoltaic	13.2 - 20.28
Line Focus Distributed Collector	22.6 - 76.9

Table 22 : The Supply Characteristics and Cost of Hydrams

Models	4 X 2			6 X 3			8 X 4		
h/H1	lit/min[1] Delivered	Equivalent Annual Energy Generation (kWh)	LAC (Rs)	lit/min[1] Delivered	Equivalent Annual Energy Generation (kWh)	LAC (Rs)	lit/min[1] Delivered	Equivalent Annual Energy Generation (kWh)	LAC (Rs)
2	175	1622.5	1.17	325	3013.3	1.12	450	4172.2	1
4	85	1576.2	1.2	215	3986.8	0.85	365	6768.25	0.62
6	65	1807	1.05	171	4756.3	0.71	305	8483.5	0.49
8	52	1928.5	0.9	145	5377.5	0.63	260	9642.44	0.4357
10	43	1993.4	0.95	125	5794.7	0.58	220	10198.74	0.411
12	36	2002.6	0.94	110	6119.24	0.55	193	10734.5	0.39
14	33	2141.73	0.88	100	6490.1	0.52	173	11227.9	0.37
16	28	2076.83	0.91	90	6675.5	0.5	157	11645.1	0.36
18	25	2086.1	0.91	82	6842.4	0.49	144	12015.97	0.34
20	22	2039	0.93	75	6953.68	0.48	133	12331.2	0.32
22	21	2141.74	0.88	68	6935.14	0.49	125	12748.42	0.32
24	19	2113.92	0.89	64	7120.57	0.47	116	12906.04	0.32
26	17	2049	0.92	57	6870.24	0.49	108	13017.3	0.32
28	15	1947.03	0.97	52	6749.71	0.5	98	12720.6	0.33
30	13	1807.95	1.05	50	6953.68	0.48	90	12516.63	0.33
Capital Cost[2]		Rs. 12350			Rs. 22100			Rs. 27300	

Source : 1. Technical brochure of Premier Irrigation Equipment Limited, Calcutta

2. Personal communication with the manufacturers

Appendix II

Enduse Specification for Energy Technologies

[[TECHNOLOGY RELATED PARAMETERS]]
TECHNOLOGY = [BIOGAS]

1 Dung needed (kg/m^3) for Biogas (80% Moisture) = 25
2 Water needed in ltrs/m^3 of biogas = 25
3 Manure in kg/m^3 of Biogas = 9 75
4 FRR for cooking (ltr kerosene/m^3) = 341
5 FRR in kg of wood per m^3 of biogas = 2 871
6 FRR in kg of Dung cake per m^3 of biogas = 6 558
7 FRR in kg of Twig stalks per m^3 of biogas = 3 649
8 FRR for irrigation (KWhr of electricity/m^3) = 1 1
9 FRR in Ltr of diesel per m^3 of biogas = .529
10 FRR for lighting (KWhr of electricity/m^3) = 4
11 FRR for lighting (ltr of kerosene/m^3) = 6
12 System life (in years) = 20
13 Cattle needed per m^3 of biogas = 2

[[TECHNOLOGY RELATED PARAMETERS]]
TECHNOLOGY = [WINDMILL]

1 Maximum Power Coeficient for Multivane Rotors = 4
2. Maximum Power Coeficient for Sail Rotors = 35
3. Maximum Power Coeficient for Savonious Rotors = .2
4 Maximum Efficiency of Reciprocating Pumps = .8
5 Mean Annual Power Coeficient (Hydraulic Efficiency) = .1
6. AFR for 4.9m Blade Size (in Ltrs of Diesel) = 150
7. AFR for 4.9m Blade Size (in KWhrs of Electricity) = 250
8. System Life (in Years) = 10

[[TECHNOLOGY RELATED PARAMETERS]]
TECHNOLOGY = [SOLAR PHOTOVOLTAICS]

1. Maximum Efficiency of Photovoltaic Arrays = .095
2. Maximum Efficiency of Motor-Pump Combination = 38
3. Mean Annual Efficiency of Photovoltaic Array-Motor-Pump = .002
4. AFR/m^2 for 5KWhr/m^2 of GSR for Irrign (Ltrs of Diesel) = 111
5. AFR/m^2 for 5KWhr/m^2 of GSR for Irrign (KWhrs of Electy.) = 164
6. AFR/m^2 for 6KWhr/m^2 of GSR for Lightg.(Ltrs of Kerosene) = 176
7. AFR/m^2 for 6KWhr/m^2 of GSR for Lightg.(KWhrs of Electy.) = 117
8. System Life (in Years) = 15

```
                    [[  TECHNOLOGY  RELATED  PARAMETERS   ]]
TECHNOLOGY = [ SOLAR THERMAL ]

    1. Solar Collector Efficiency =  .3
    2. Water inlet temperature (in deg. celsius) =  20
    3. Water outlet temperature (in deg  celsius) =  60
    4. AFR/m^2 for 6KWhr/m^2 of GSR (Water htg.KWhrs of Electy.) =  900
    5. AFR/m^2 for 6KWhr/m^2 of GSR (Water htg.Kgs of Fuel Oil) =  150
    6. AFR/m^2 for 6KWhr/m^2 of GSR for Cookg.(Kgs of Fuel wood) =  1095
    7. AFR/m^2 for 6KWhr/m^2 of GSR for Cookg (Ltrs of Kerosene) =  130
    8  AFR/m^2 for 6KWhr/m^2 of GSR for Cookg (Kgs of Twig stalks) =  2410
    9. AFR/m^2 for 6KWhr/m^2 of GSR for Cookg.(Kgs of Dung cake) =  1391
   10. System Life (in Years) =  10
```

```
                 [[  TECHNOLOGY .RELATED  PARAMETERS  ]]
HNOLOGY = [ BIOMASS GASIFIER ]

  1. Carbon monoxide gas production (in m^3) / 1 kg of Wood =  2 8
  2  Calorie value of wood gas (in Kcal / m^3) =  1100
  3. Motive power conversion efficiency (in %) =  70
  4  FRR (in Ltrs of diesel) for Irrigation per 1 Kg of wood =  303
  5  FRF (in KWhrs of electricity) for Irrigation per 1 Kg of wood =  1.05
  6  FRR (in Kgms of Fuel oil) for Water heating per 1 Kg of wood =  3
  7  Ash in 1 Kg of biomass fuel (wood) =   05
  8  System Life (in years) =  10
```

Source : Thukral and Joshi (1987)